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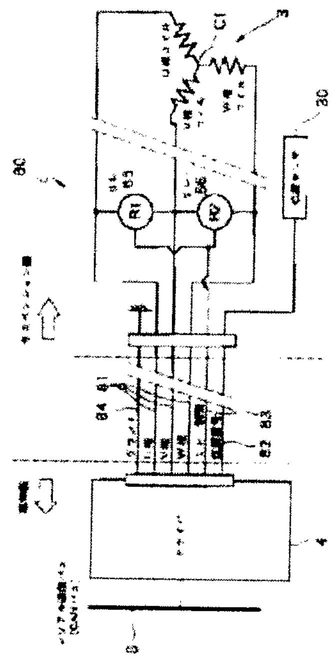
(54) ELECTROMAGNETIC SUSPENSION APPARATUS

(57)Abstract:
PROBLEM TO BE SOLVED: To provide an electromagnetic suspension apparatus capable of developing a damping force with a motor, when it is impossible to control the electromagnetic suspension apparatus due to cable disconnection or the like (when there is no control).
SOLUTION: When a disconnection of a power cable 81 is detected, a relay control signal is turned off to close a first and second relays 65, 66, and short- circuit a U-phase coil, V-phase coil and W-phase coil via the first and second relays 65, 66. Consequently, when a suspension unit strokes, the motor 3 arranged in the suspension unit operates as a generator, and the resistance of the magnitude being substantially proportional to a stroke speed, that is the damping force, is developed.



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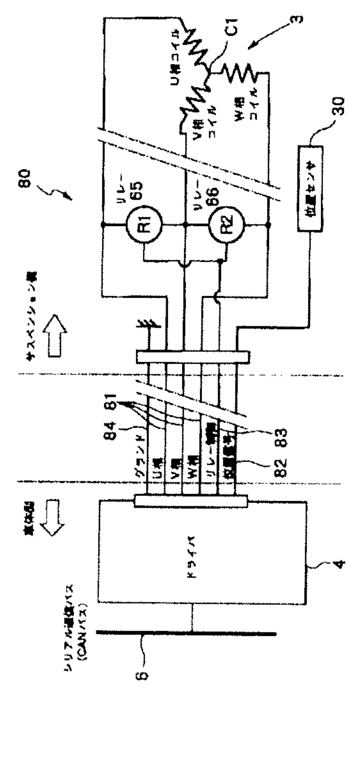
(54)【発明の名称】　電磁サスペンション装置

(57)【要約】

【課題】　ケーブル断線などにより電磁サスペンション装置の制御が不能の場合（無制御時）、モータで減衰力の発生を可能とした電磁サスペンション装置を提供する。

【解決手段】　動力ケーブル８１の断線を検知した場合、リレー制御信号をＯＦＦし第１、第２リレー６５，６６を閉じさせ、第１、第２リレー６５，６６を介してＵ相コイル、Ｖ相コイル及びＷ相コイルを短絡させる。このため、サスペンションユニットがストロークした際、サスペンションユニットに設けられたモータ３は発電機として作動し、ストローク速度にほぼ比例した大きさの抵抗すなわち減衰力を発生する。



【特許請求の範囲】

【請求項１】　相対的に変位可能に一対の変位部材を設け、前記一対の変位部材のいずれか一方に磁石部材を設け、いずれか他方に前記磁石部材と共にモータを構成するコイル部材を設け、前記コイル部材への通電により前記磁石部材との間に生じる電磁力によって推進力を得、前記コイル部材及び前記磁石部材の相対変位により前記コイル部材に生じる起電力によって減衰力を得るサスペンションユニットと、該サスペンションユニットへの通電を制御する制御手段とを備えた電磁サスペンション装置において、制御手段からサスペンションユニットへ供給される信号の異常を検知する異常検知手段と、コイル部材が閉ループを構成するようにする短絡回路とを設けたことを特徴とする電磁サスペンション装置。

【請求項２】　前記制御手段を車体側に設けるとともに該制御手段と前記サスペンションユニットとをケーブルで接続し、さらに前記短絡回路をサスペンションユニットと一体に設けたことを特徴とする請求項１記載の電磁サスペンション装置。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、電磁力による振動抑制用アクチュエータ、ダンパに係り、特に、自動車、二輪車、鉄道車両、構造物及び建造物などに用いて好適な電磁サスペンション装置に関する。

【０００２】

【従来の技術】従来の電磁サスペンション装置の一例として、油圧ダンパのオリフィス等の減衰力発生機構に代えて、回転型モータ及びこの回転型モータのロータの回転動を直線動に変換する直動—回転動変換機構を用いたり、あるいは直動型モータを用いた電磁サスペンション装置がある。この電磁サスペンション装置は、通電することにより可動部を変位させモータを本来のモータ（アクチュエータ）としてアクティブに動作させる一方、モータを発電機として使用することにより(パッシブに)減衰力を発生させるようにしている。

【０００３】前記モータを発電機として使用する場合、モータ（発電機）に発生する抵抗力、すなわち減衰力は、コイルに流れる電流の大きさに比例するので、減衰力を可変とするためには、コイルに流れる電流の大きさを調整すればよい。コイルに流れる電流を調整するには、回路内に可変抵抗を設けたり、回路をオン、オフ（ＯＮ／ＯＦＦ）するスイッチを設け、スイッチのオン、オフ時間比を制御することなどで容易に実現できる。

【０００４】そのため、電磁サスペンション装置の減衰力をストローク速度やストローク位置に応じて可変制御したり、制御対象の振動を抑制するようにリアルタイムに可変制御する、いわゆるセミアクティブダンパとして構成することは比較的容易である。また、このようにセミアクティブダンパとして構成する（発電機として使用する）場合、電磁サスペンション装置に電気エネルギーを与える必要はなく、消費電力を非常に低く抑えることができる。

【０００５】また、電磁サスペンション装置に電気エネルギーを与えてモータとして使用すれば、容易に任意の力を発生させることができるため、力を加えて減衰力を大きくしたり、任意の制御力を発生させてアクティブサスペンションとして動作させ、振動抑制効果を高めることが可能であり、このようにして振動抑制効果を高める方法も提案されている。前記電磁サスペンション装置でモータとしては直流モータや同期モータが用いられている。

【０００６】

【発明が解決しようとする課題】ところで、前記電磁サスペンション装置においてセンサ部を除いた駆動系統は、電源、モータ駆動回路及び推進力、減衰力を発生させるモータから大略構成されている。現状では、電源とモータは、一体化が困難であり分離されているため、電源とモータ間には両者を接続するケーブルが必要となる。通常、電源部—モータ駆動回路間、及びモータ駆動回路—モータ間はケーブルで接続されている。しかし、これらのケーブルが断線したり、モータ駆動回路内で断線が発生した場合（無制御時）、モータは推進力を発生できないばかりか、減衰力も発生できず、モータが無減衰の状態になってしまうという課題がある。また、イグニッションキーがオン（ＯＮ）されていない場合、あるいはバッテリ上がり等の場合（無制御時）、モータ駆動回路やモータに電力が供給されず、上述と同様にモータが無減衰の状態になってしまうという課題がある。

【０００７】本発明は、上記事情に鑑みてなされたもので、ケーブル断線などにより電磁サスペンション装置の制御が不能の場合（無制御時）、モータで減衰力の発生を可能とした電磁サスペンション装置を提供することを目的とする。

【０００８】

【課題を解決するための手段】請求項１記載の発明は、相対的に変位可能に一対の変位部材を設け、前記一対の変位部材のいずれか一方に磁石部材を設け、いずれか他方に前記磁石部材と共にモータを構成するコイル部材を設け、前記コイル部材への通電により前記磁石部材との間に生じる電磁力によって推進力を得、前記コイル部材及び前記磁石部材の相対変位により前記コイル部材に生じる起電力によって減衰力を得るサスペンションユニットと、該サスペンションユニットへの通電を制御する制御手段とを備えた電磁サスペンション装置において、制御手段からサスペンションユニットへ供給される信号の異常を検知する異常検知手段と、コイル部材が閉ループを構成するようにする短絡回路とを設けたことを特徴とする。請求項２記載の発明は、請求項１記載の構成にお

いて、前記制御手段を車体側に設けるとともに該制御手段と前記サスペンションユニットとをケーブルで接続し、さらに前記短絡回路をサスペンションユニットと一体に設けたことを特徴とする。

【0009】

【発明の実施の形態】本発明の第1実施の形態に係る電磁サスペンション装置を図1～図6に基づいて説明する。

【0010】図1及び図2において、電磁サスペンション装置1は自動車に用いられるものであり、各車輪側部材と車体との間に介装される4本のサスペンションユニットを有している。右前輪側部材、左前輪側部材、右後輪側部材及び左後輪側部材にそれぞれ対応するサスペンションユニットを、右前輪側、左前輪側、右後輪側及び左後輪側サスペンションユニット２ＦＲ，２ＦＬ，２ＲＲ，２ＲＬという。右前輪側、左前輪側、右後輪側及び左後輪側サスペンションユニット２ＦＲ，２ＦＬ，２ＲＲ，２ＲＬには、それぞれ、スター結線されたＵ相コイル、Ｖ相コイル及びＷ相コイル（符号省略）からなる3相同期形のモータ（それぞれ、右前輪側、左前輪側、右後輪側及び左後輪側モータ３ＦＲ，３ＦＬ，３ＲＲ，３ＲＬという。）が備えられている。右前輪側、左前輪側、右後輪側及び左後輪側サスペンションユニット２ＦＲ，２ＦＬ，２ＲＲ，２ＲＬは同等構成を成しており、以下、適宜サスペンションユニット２と総称する。また、右前輪側、左前輪側、右後輪側及び左後輪側モータ３ＦＲ，３ＦＬ，３ＲＲ，３ＲＬについても同様に、適宜モータ３と総称する。

【0011】右前輪側、左前輪側、右後輪側及び左後輪側モータ３ＦＲ，３ＦＬ，３ＲＲ，３ＲＬにはそれぞれドライバ(それぞれ、右前輪側、左前輪側、右後輪側及び左後輪側ドライバ４ＦＲ，４ＦＬ，４ＲＲ，４ＲＬという。)が接続されており、モータ３を駆動するようにしている。右前輪側、左前輪側、右後輪側及び左後輪側ドライバ４ＦＲ，４ＦＬ，４ＲＲ，４ＲＬは同等構成を成しており、以下、適宜ドライバ４と総称する。ドライバ４は、各車輪に対応するサスペンションタワー部に設けられている。ドライバ４にはＤＣ３６Ｖのモータ用電源５が接続されている。

【0012】ドライバ４には、シリアル通信バス６を介して制御手段としての制御装置７（振動、姿勢制御手段）が接続されており、制御装置７からドライバ４への動作指令や、ドライバ４から制御装置７への各種フィードバックなどは全てシリアル通信〔例えばＣＡＮ（Controller Area Network）仕様に準拠したシリアル通信〕によって行われるようにしている。シリアル通信のプロトコルは、制御装置７からの「コマンド」とドライバ４からの「レスポンス」がセットになったもので、一定間隔（例えば５ｍｓ）〔制御装置７の制御周期〕毎に常に「コマンド」と「レスポンス」が授受される。

【0013】また、例えば制御装置７からドライバ４への「コマンド」が一定時間（例えば２０ｍｓ）以上送信されない、あるいはドライバ４から制御装置７への「レスポンス」が一定時間（例えば２０ｍｓ）以上送信されない、といった場合は、制御装置７又はドライバ４はシステム異常と判断し、「モータ用電源５の切断」、「エラー表示」などの異常処理を行う。シリアル通信バス６には、ＡＢＳ（Anti-lock Break System）制御装置８及びＶＤＣ（Vehicle Dynamics Control）制御装置９が接続されている。ＡＢＳ制御装置８及びＶＤＣ制御装置９は、車両の走行安定性を確保するようにしたものである。本電磁サスペンション装置１、ＡＢＳ制御装置８及びＶＤＣ制御装置９は協調して動作することができるようになっている。

【0014】制御装置７は、モータ３への通電ひいてはモータ３による推進力発生制御を行うと共に、モータ３の起電力発生（発電機としての使用）による減衰力制御を行うようにしている。制御装置７には、車体の上下振動を検出する３個の上下加速度センサ（以下、第１、第２、第３上下加速度センサという。）１０，１１，１２、車輪速センサ１３、ハンドル角センサ１４、ブレーキセンサ１５及びＤＣ１２Ｖの電源（以下、１２Ｖ電源という。）１６が接続されている。制御装置７には更に、システム診断などに用いる外部通信機器１７が接続されている。第１上下加速度センサ１０は右前輪のサスペンションタワー部に設けられ、第２上下加速度センサ１１は左前輪のサスペンションタワー部に設けられ、第３上下加速度センサ１２は後部トランク部に設けられている。

【0015】サスペンションユニット２は、図２に示すように、車両の車体側に保持される外筒部材２０（一対の変位部材のうち一方）と、外筒部材２０に相対変位可能に一端側が挿嵌され他端側が車両の車軸側に保持されるロッド２１（一対の変位部材のうち他方）とを備えている。外筒部材２０とロッド２１との間になるようにして、外筒部材２０の内側には複数のコイル２２（コイル部材）が軸方向に所定長さにわたって設けられ、ロッド２１の外側には永久磁石（磁石部材）２３が軸方向に所定長さにわたって設けられている。

【0016】コイル２２とロッド２１（永久磁石２３）との間になるようにして、コイル２２の内側に筒状の案内部材（以下、第１案内部材という。）２４が設けられ、ロッド２１の一端部には第１案内部材２４に摺動する摺動部（以下、第１摺動部という。）２５が設けられている。外筒部材２０の開口端には環状の案内部材（以下、第２案内部材という。）２６が装着されている。第２案内部材２６の内側には、ロッド２１に摺動してその動きを案内する摺動部（以下、第２摺動部という。）２７が設けられている。ロッド２１は、第１摺動部２５及び第２摺動部２７によって外筒部材２０に対して摺動可

能に支持されている。

【００１７】前記コイル２２は、Ｕ相、Ｖ相、Ｗ相が軸方向に交互に並んだ構成になっている。永久磁石２３は、Ｎ極、Ｓ極が軸方向に交互に並んだ構成になっている。コイル２２に通電するとコイル２２と永久磁石２３との間に軸方向の推力が発生し外筒部材２０とロッド２１は相対変位（ストローク）する。推力の向きはコイル２２の通電方向に基づいて定まる。本実施の形態では、コイル２２、永久磁石２３、コイル２２を支持する外筒部材２０、及び永久磁石２３を支持するロッド２１などから前記モータ３が構成されている。また、外筒部材２０及びロッド２１ひいてはコイル２２及び永久磁石２３が相対変位すると、コイル２２には起電力が生じ、モータ３は発電機の作用をなすようになっている。サスペンションユニット２のモータ３には位置センサ３０（図４参照）が設けられており、コイル２２及び永久磁石２３ひいては外筒部材２０とロッド２１の相対変位（ストローク）を検出し得るようになっている。

【００１８】制御装置７は、本電磁サスペンション装置１の制御プログラムや定数などの固定的なデータを記憶するＲＯＭ３１と、前記制御プログラムを実行し、本電磁サスペンション装置１全体の制御を司るＣＰＵ３２と、ＣＰＵ３２の演算結果等を一時的に記憶するＲＡＭ３３と、サンプリング時間等を生成するタイマ３４とを備えている。制御装置７は、さらに、第１、第２、第３上下加速度センサ１０，１１，１２からのアナログ信号をデジタル信号に変換するＡ／Ｄ変換器３５と、車輪速センサ１３、ハンドル角センサ１４及びブレーキセンサ１５からの信号を処理するセンサｉ／ｏインタフェース（センサｉ／ｏ　ｉ／ｆ）３６と、ドライバ４などとのシリアル通信用のＣＡＮインターフェース３７と、１２Ｖ電源１６をＣＰＵ３２などが必要とする５Ｖ、３．３Ｖなどの電圧に変換するＤＣ／ＤＣ電源ユニット３８と、外部通信機器１７に対して信号を授受する外部通信機器インターフェース３９とを備えている。本実施の形態では、消費電力制限手段はＲＯＭ３１に記憶されている制御装置７の制御プログラムの中の１シーケンスとして構成される。

【００１９】本電磁サスペンション装置１では、車両の状態のうち車体の上下振動については上述したように第１、第２、第３上下加速度センサが検出する。また、車体のロール、ピッチング量については、前記位置センサ３０の検出信号、ひいては各車輪のサスペンションユニット２のストロークに基づいて判断する。また、車両の状態の検出は、前記第１、第２、第３上下加速度センサ１０，１１，１２及び位置センサ３０に限らず、車輪速センサ１３、ハンドル角センサ１４、ブレーキセンサ１５によっても行うようにしている。

【００２０】制御装置７は、前記第１、第２、第３上下加速度センサ１０，１１，１２、位置センサ３０、車輪速センサ１３、ハンドル角センサ１４、ブレーキセンサ１５からの信号に基づいて、車両の振動、姿勢の変化や不安定な車両挙動を抑制するように、また、車速や運転者のハンドル、アクセル、ブレーキ操作に対して車両がより安定するように各輪のサスペンションユニット２の制御量を決定し、ドライバ４に対してモータ３の駆動信号を送るようにしている。

【００２１】ドライバ４は、図４に示すように、モータ駆動用制御プログラムや定数などの固定的なデータを記憶するＲＯＭ（以下、ドライバＲＯＭという。）４０と、前記モータ駆動用制御プログラムを実行し、制御装置７との通信制御を行うと共にドライバ４の制御を司るＣＰＵ（以下、ドライバＣＰＵという。）４１と、ドライバＣＰＵ４１の演算結果等を一時的に記憶するＲＡＭ（以下、ドライバＲＡＭという。）４２と、車両及び運転者などに固有とされ、書き換え可能なパラメータ等を記憶するＦＬＡＳＨメモリ４３と、サンプリング時間等を生成するタイマ（以下、ドライバタイマという。）４４とを備えている。

【００２２】ドライバ４は、さらに、モータ３駆動用のＰＷＭ信号生成器４５と、モータ用電源５（ＤＣ３６Ｖ）にＤＣバス４７を介して接続され、モータ用電源５からの電流をモータ３の駆動に使用するように３相電流に変換しこの電流をモータ接続線４８を介してモータ３に出力するＦＥＴ４９と、前記モータ接続線４８に設けられモータ３の駆動電流を検出する電流検出器５１と、モータ接続線４８の出力側に設けられるラインフィルタ５３と、を備えている。又、ドライバ４は、電流検出器５１からのアナログ信号をデジタル信号に変換するＡ／Ｄ変換器（以下、ドライバＡ／Ｄ変換器という。）５４と、前記位置センサ３０からの信号をディジタル信号に変換してドライバＣＰＵ４１に入力する位置センサインターフェース（位置センサｉ／ｆ）５５と、ドライバＣＰＵ４１からのリレー制御信号を第１、第２リレー６５，６６に入力するリレーインターフェース（リレーｉ／ｆ）６０と、を備えている。

【００２３】第１、第２リレー６５，６６は、リレー制御信号を入力可能とした励磁コイル(図示省略)と、励磁コイルに入力するリレー制御信号に応じて開閉する定常時閉の接点部(図示省略)とを備えており、定常時閉形のリレーとされている。そして、励磁コイルのリレー制御信号がオン（ＯＮ）の場合に前記接点部〔ひいては第１、第２リレー６５，６６は〕が開（ＯＦＦ）とされるようになっている。この実施の形態では、電源の投入〔イグニッションスイッチのオン作動〕によりリレー制御信号がオン（ＯＮ）されて第１、第２リレー６５，６６は開（ＯＦＦ）とされ、通常時、この状態〔第１、第２リレー６５，６６は開（ＯＦＦ）状態〕が維持される。なお、後述するように、各種ケーブルの断線等の故障発生時〔無制御時〕には、リレー制御信号がオフ（Ｏ

ＦＦ）されて第１、第２リレー６５，６６は閉（ＯＮ）とされることになる。

【００２４】ドライバ４には、さらに、ＤＣバス４７の電圧を監視する過電圧検出器５６と、ＦＥＴ４９の過熱を検出する過熱検出器５７と、制御装置７とのシリアル通信インターフェースであるＣＡＮｉ／ｆ（以下、ドライバＣＡＮインターフェースという。）５８と、モータ用電源５をドライバＣＰＵ４１など他の部材の動作に必要な５Ｖ、１２Ｖ、１５Ｖなどの電圧に変換するＤＣ／ＤＣ電源ユニット（以下、ドライバＤＣ／ＤＣ電源ユニットという。）５９とが備えられている。

【００２５】ドライバ４は、シリアル通信バス６を介し、制御装置７から「サーボＯＮ」などの制御コマンド及び実際にモータ３を駆動させる制御量等を受け取ると、サンプリング時間（ドライバ４の制御周期）毎に位置センサ３０の信号からモータ３内のＵ相、Ｖ相、Ｗ相コイル２２と永久磁石２３の作る磁気回路との間の位相角（電気角）、モータ３の動作速度、電流検出器５１の信号からコイル２２の電流値、電圧値を取得し、制御装置７からのモータ駆動指令通りのモータ動作となるようにＰＷＭ信号生成器４５を調節する。前記ドライバ４の制御周期は、制御装置７の制御周期（例えば５ｍｓ）よりも充分速く、例えば２５０μｓに設定されている。

【００２６】この電磁サスペンション装置１では、車体の上下振動に伴いロッド２１及び外筒部材２０が相対的に変位すれば、コイル２２には起電力が発生する。すなわち、モータ３は発電機として作用し、コイル２２に電流が流れることにより、サスペンションユニット２（モータ３）はロッド２１及び外筒部材２０の相対速度に応じた抵抗力、すなわち減衰力を発生することになる。また、ロッド２１と外筒部材２０との相対的な位置関係（電気角）、ひいては車体の上下振動状態に応じて、コイル２２に電流を流せば、モータ３は本来のモータ（アクチュエータ）として作用して推進力を発揮することになり、サスペンションユニット２は振動抑制効果を向上できるようにしている。

【００２７】図５にケーブル断線時にコイル２２を短絡させる回路（短絡回路）８０を示す。短絡回路８０は、Ｕ相コイルの一端（Ｕ相コイル、Ｖ相コイル及びＷ相コイルの共通接続端子Ｃ１に対して反対側の端子部）とＶ相コイルの一端（共通接続端子Ｃ１に対して反対側の端子部）との間に介装された前記第１リレー６５と、Ｖ相コイルの一端とＷ相コイルの一端（共通接続端子Ｃ１に対して反対側の端子部）との間に介装された前記第２リレー６６とを備え、後述するように、Ｕ相コイル、Ｖ相コイル及びＷ相コイルを第１、第２リレー６５，６６を介して短絡し得るようにしている。短絡回路８０は、サスペンションユニット２に設けられている。

【００２８】車体側に取付けられたドライバ４とサスペンションユニット２（モータ３）とは、モータ３のＵ相コイル、Ｖ相コイル及びＷ相コイルに接続される動力ケーブル８１と、位置センサ３０から延びる位置信号用ケーブル８２と、第１、第２リレー６５，６６制御用のケーブル（リレー制御用ケーブル）８３と、グランドケーブル８４とを介して接続されている。また、第１、第２、第３上下加速度センサ１０，１１，１２と制御装置７とは加速度信号ケーブル８５を介して接続されている。この実施の形態では、前記各ケーブル〔動力ケーブル８１、位置信号用ケーブル８２、リレー制御用ケーブル８３、加速度信号ケーブル８５〕が断線された場合や、バッテリ〔１２Ｖ電源１６、モータ用電源５〕から電力が供給されていない（以下、適宜、電源断という。）場合等の故障が発生したとき（無制御時）には、ドライバ４は、リレー制御信号をオフ（ＯＦＦ）して第１、第２リレー６５，６６に出力するようにしている。

【００２９】上述したように第１、第２リレー６５，６６は定常時閉形のリレーで、かつ通常時にはドライバ４からリレー制御信号がＯＮとされて出力されており、第１、第２リレー６５，６６は開いた（ＯＦＦした）状態にされている。この通常時には、第１、第２リレー６５，６６が開されていることから、Ｕ相コイル、Ｖ相コイル及びＷ相コイルは短絡されておらず、モータ３は正常に制御され、推進力のの発生（本来のモータとして作動）及び減衰力の発生（発電機としての作動）を行ない得るようになっている。

【００３０】ドライバ４からリレー制御信号が出力されない（リレー制御信号がＯＦＦとされる）場合、第１、第２リレー６５，６６は閉（ＯＮ）〔定常時と同等の状態〕とされ、Ｕ相コイル、Ｖ相コイル及びＷ相コイルは、第１、第２リレー６５，６６が閉じる（ＯＮする）ことから短絡された状態となる。すなわち、上述したように無制御時〔前記各ケーブルの断線時、電源断時〕には、ドライバ４は、リレー制御信号をオフ（ＯＦＦ）して第１、第２リレー６５，６６に出力するので、第１、第２リレー６５，６６は閉じられてＵ相コイル、Ｖ相コイル及びＷ相コイルは短絡された状態となる。

【００３１】そして、Ｕ相コイル、Ｖ相コイル及びＷ相コイルが短絡されていると、サスペンションユニット２がストロークした際、モータ３は発電機として作動し、ストローク速度にほぼ比例した大きさの抵抗すなわち減衰力を発生する。以下、具体的な断線箇所を例にして断線の検知方法（異常検知手段）及びその際の制御方法について説明する。動力ケーブル８１（ドライバ４及びモータ３間のケーブル）の断線検知は、次のようにして行なう。

【００３２】すなわち、ドライバ４には、電流検出器５１が組み込まれており、ドライバＣＰＵ４１の指令したＵ相コイル、Ｖ相コイル及びＷ相コイルへの電流値が正確に出力されているかどうかを出力される電流を検出することによりチェックし、その検出値をドライバＣＰＵ

４１へフィードバックしている。そして、動力ケーブル８１が断線した場合には、ドライバＣＰＵ４１にフィードバックされる電流値が異常な値（電流値がゼロまたは極めて小さい値）を呈することとなる。ドライバＣＰＵ４１は、このことを利用して動力ケーブル８１の断線の有無を判定する。

【００３３】ドライバＣＰＵ４１は、動力ケーブル８１が断線有と判定した（動力ケーブル８１の断線を検知した）場合、リレー制御信号をＯＦＦし第１、第２リレー６５，６６を閉じさせ、第１、第２リレー６５，６６を介してＵ相コイル、Ｖ相コイル及びＷ相コイルを短絡させた状態とすると共に、モータ制御を停止し、制御装置７へ断線検知を通知する。

【００３４】次に、位置信号用ケーブル８２の断線判断は、次のように行なう。位置センサ３０が常時信号を出力するタイプのセンサ（例えば、信号が１－５Ｖの間で変化する）の場合は信号が出力されないときに断線と判断できる。また、例えば、０－５ＶのＡ，Ｂ相パルスの位置センサの場合等、出力信号が出力されない状態が存在するセンサの場合は、制御装置７に接続される上下加速度センサ等からの出力から当然位置センサ３０の出力が変化すべきであるのに出力が０Ｖや変化しない場合に、位置信号用ケーブル８２の断線または位置センサ３０の故障と判断できる。位置信号用ケーブル８２の断線を検知した場合、制御装置７はドライバ４へモータ制御停止を通知する。そして、ドライバＣＰＵ４１は、上述と同様にしてＵ相コイル、Ｖ相コイル及びＷ相コイルの短絡、モータ制御の停止及び制御装置７へ断線検知の通知を行なう。

【００３５】リレー制御用ケーブル８３の断線は次のように検知される。ここで、第１、第２リレー６５，６６を開く（ＯＦＦする）には、リレー制御用ケーブル８３に励磁電流〔リレー制御信号の内容（又は信号レベル）がＯＮとされたリレー制御信号〕を流し、第１、第２リレー６５，６６に内蔵されている前記励磁コイルを励磁する必要がある。そして、通常時リレー制御用ケーブル８３の断線は、ドライバ４内のリレーｉ／ｆ６０によって励磁電流（リレー制御信号）を監視して検出するようにしている。リレー制御用ケーブル８３の断線を検知した場合、第１、第２リレー６５，６６には、信号が供給されないので自動的に閉じられ（定常時の状態に戻る）、Ｕ相コイル、Ｖ相コイル及びＷ相コイルを短絡させた状態となる。さらに、ドライバＣＰＵ４１はリレー制御信号をＯＦＦにすると共に、モータ制御を停止し、制御装置７へ断線検知を通知する。ここで、リレー制御信号をＯＦＦにする理由は、リレー制御用ケーブルが完全に断線された場合は問題ないが、断線後、再び接続、断線を繰り返すような場合、第１、第２リレー６５，６６が開閉を繰り返してしまうので、これを防止するために、リレー制御信号をＯＦＦにしておく必要がある。

【００３６】また、加速度信号ケーブル８５の断線は次のように検知される。この実施の形態では、第１、第２、第３上下加速度センサ１０，１１，１２からの加速度信号は、例えば３Ｖを中心に１～５Ｖの信号出力としておき、第１、第２、第３上下加速度センサ１０，１１，１２から信号が出力されないとき（例えば、第１、第２、第３上下加速度センサ１０，１１，１２の出力信号が０Ｖのとき）は、加速度信号ケーブル８５の断線であると判断できるように定めている。そして、ドライバＣＰＵ４１は、第１、第２、第３上下加速度センサ１０，１１，１２からの加速度信号に基づいて加速度信号ケーブル８５の断線検出を行う。そして、断線を検知した場合、ドライバＣＰＵ４１は、上述と同様にしてＵ相コイル、Ｖ相コイル及びＷ相コイルの短絡、モータ制御の停止及び制御装置７へ断線検知の通知を行なう。

【００３７】また、制御装置７やドライバ４が暴走などによって正常に動作しなくなった場合も、ドライバＣＰＵ４１はモータ３への電力供給を停止すると共に、第１、第２リレー６５，６６を閉じ、Ｕ相コイル、Ｖ相コイル及びＷ相コイルを短絡させた状態とする。この暴走の有無の判断は、例えばリレーｉ／ｆとＰＷＭ信号生成器とにＣＰＵから定期的にアクセスするように設定し、リレーｉ／ｆやＰＷＭ信号生成器に、この定期的アクセスの有無を判断し、無い場合に出力を停止する機能を設けることにより、暴走した際には、定期的アクセスが行なわれなくなるので、リレーｉ／ｆとＰＷＭ信号生成器からの出力が停止して、モータ３への電力供給を中止し、Ｕ相コイル、Ｖ相コイル及びＷ相コイルを短絡させた状態とする。また、モータ用電源５とドライバ４を接続する電源用ケーブル８６が断線し、ドライバ４への電力供給が停止した場合、リレー制御信号はＯＦＦされ、第１、第２リレー６５，６６が閉じられ、Ｕ相コイル、Ｖ相コイル及びＷ相コイルを短絡させた状態とする。

【００３８】また、システムの正常動作中に第１、第２リレー６５，６６が何らかの要因で閉じる（ＯＮする）等の異常動作をした場合、Ｕ相コイル、Ｖ相コイル及びＷ相コイルの手前で短絡ループ（閉回路）が形成され、Ｕ相コイル、Ｖ相コイル及びＷ相コイルへはドライバ４から電流が供給されなくなる。この場合、コイル２２の抵抗が取り除かれた分だけ動力ケーブル８１には過大な電流が流れることになり、電流検出器５１による電流値フィードバックの異常（電流値過大）が検出されるため、ドライバＣＰＵ４１は第１、第２リレー６５，６６の異常を検出することができる。

【００３９】そして、第１、第２リレー６５，６６の異常を検知した場合、ドライバＣＰＵ４１は、上述と同様にしてＵ相コイル、Ｖ相コイル及びＷ相コイルの短絡、モータ制御の停止及び制御装置７へ断線検知の通知を行なう。

【００４０】以上の動作を図６のフローチャートに基づ

いて要約的に説明する。ドライバＣＰＵ４１は制御装置７からの制御コマンドを取り込み(ステップＳ１１)、制御装置７からの異常処理要求があるか否かを判断する(ステップＳ１２)。ステップＳ１２でＮｏ（異常処理が必要でない）と判断した場合は、ドライバＣＰＵ４１はモータ３の制御のために位置センサ３０からの位置データを読み込む(ステップＳ１３)。

【００４１】ステップＳ１３の位置データの読み込みにより位置信号用ケーブル８２の断線の有無を判断する(ステップＳ１４)。次のステップ１５で、モータ制御ロジックを実行し、位置データからモータ３の磁石２３とコイル２２の位置関係、電流値フィードバック（１サンプリング前）からＵ相コイル、Ｖ相コイル及びＷ相コイルの電流値等を把握し、必要とするトルクやモータ３の速度などからモータ３への制御量を決定する。

【００４２】次に、ＰＷＭ信号生成器４５を介してＦＥＴ４９をスイッチングしてＵ相コイル、Ｖ相コイル及びＷ相コイルに印加する電圧を調整し、モータ３が所定のトルクを発生しかつ所定の速度をとなるように制御する(ステップＳ１６)。その後、電流検出器５１でＵ相コイル、Ｖ相コイル及びＷ相コイルの電流値フィードバックを取り込み(ステップＳ１７)、断線の有無を判断する(ステップＳ１８)。

【００４３】ステップＳ１２でＹｅｓ（異常処理が必要である）と判断した場合、またはステップＳ１４でＹｅｓ（断線有り）と判断した場合は、モータ３の動力を断つと共に、第１、第２リレー６５，６６の短絡、制御装置７への異常処理ステータスの送信などの異常処理を行なう(ステップＳ１９)

【００４４】上述したように、電源断、各種ケーブルの断線、バッテリ上がり（電源断）、制御装置７やドライバ４の暴走、イグニッションスイッチのオフ等のいわゆる無制御時でもサスペンションユニット２は減衰力を発生することができ、安全性が大幅に向上する。

【００４５】なお、第１、第２リレー６５，６６は、大電流の通電が可能なタイプを選択すれば、破損する虞が小さくなる。そして、第１、第２リレー６５，６６として大電流の通電が可能なタイプを用いることにより、無制御時でも長時間に渡りサスペンションユニット２は安定した減衰力を発生できるようになり、安全性がさらに向上する。

【００４６】次に、本発明の第２実施の形態を図７及び図８に基づいて説明する。第２実施の形態の電磁サスペンション装置は、図７及び図８に示すように、前記ＦＥＴ４９に代えるＦＥＴ回路４９Ａを有している。ＦＥＴ回路４９Ａは、６個のＦＥＴ（以下、第１～第６ＦＥＴという。）５４１～５４６を有している。第１ＦＥＴ５４１のソース〔Ｓ〕は第２ＦＥＴ５４２のドレイン〔Ｄ〕と接続されており、その接続部はＵ相コイルに接続されている。第３ＦＥＴ５４３のソース〔Ｓ〕は第４ＦＥＴ５４４のドレイン〔Ｄ〕と接続されており、その接続部はＶ相コイルに接続されている。第５ＦＥＴ５４５のソース〔Ｓ〕は第６ＦＥＴ５４６のドレイン〔Ｄ〕と接続されており、その接続部はＷ相コイルに接続されている。

【００４７】ＰＷＭ信号生成器４５からＦＥＴ回路４９Ａに６本の制御線９０が延ばされており、そのうち３本の信号線９０が第１、第３、第５ＦＥＴ５４１，５４３，５４５（以下、適宜、上側アームのＦＥＴという。）のゲート〔Ｇ〕に接続されている。前記６本の制御線９０うち他の３本の信号線９０が第２、第４、第６ＦＥＴ５４２，５４４，５４６のゲート〔Ｇ〕にそれぞれ短絡補助回路（以下、短絡補助第１回路という。）８０Ａを介して接続されている。この第２実施の形態では、短絡補助第１回路８０Ａ及び第２、第４、第６ＦＥＴ５４２，５４４，５４６により短絡回路が形成されている。

【００４８】第１ＦＥＴ５４１は、ソース〔Ｓ〕及びドレイン〔Ｄ〕を接続するフリーホイールダイオード９１を内蔵しており、フリーホイールダイオード９１を通してソース〔Ｓ〕からドレイン〔Ｄ〕への通電を許容するようにしている。第２～第６ＦＥＴ５４２～５４６の各ソース及びドレイン間についても第１ＦＥＴ５４１と同様にフリーホイールダイオード９１が接続されている。

【００４９】第１、第３、第５ＦＥＴ５４１，５４３，５４５（上側アームのＦＥＴ）のドレイン〔Ｄ〕は、モータ用電源５のプラス（＋）端子に接続されている。また、第２、第４、第６ＦＥＴ５４２，５４４，５４６（下側アームのＦＥＴ）のソース〔Ｓ〕は、モータ用電源５のマイナス（－）端子に接続されている。

【００５０】前記短絡補助第１回路８０Ａは、ｎｐｎ形のトランジスタ（以下、第１トランジスタという。）７０と、ｐｎｐ形のトランジスタ（以下、第２トランジスタという。）７１とを備えている。第１トランジスタ７０のエミッタ（Ｅ）と第２トランジスタのエミッタ（Ｅ）とが接続されており、この接続部が第２、第４、第６ＦＥＴ５４２，５４４，５４６（下側アームのＦＥＴ）の各ゲート（Ｇ）〔図８では第２ＦＥＴ５４２のみを励磁している。〕に接続されている。第１トランジスタ７０のベース（Ｂ）と第２トランジスタのベース（Ｂ）とが接続されており、この接続部がＰＷＭ信号生成器４５の制御線９０に接続されている。第１トランジスタ７０のコレクタ（Ｃ）は１５ＶのＦＥＴゲート駆動用電源９２に接続されている。第２トランジスタ７１のコレクタ（Ｃ）は接地されている。

【００５１】第２、第４、第６ＦＥＴ５４２，５４４，５４６（下側アームのＦＥＴ）の各ドレイン（Ｄ）とゲート（Ｇ）とには、直列接続されたダイオード６７及び抵抗６８が並列に接続されている。第２、第４、第６ＦＥＴ５４２，５４４，５４６の各ゲート（Ｇ）には、接

地されたツェナーダイオード６９が接続されており、前記各ゲート（Ｇ）に高電圧が印加されないようにしている。各ツェナーダイオード６９には、コンデンサ９３が並列に接続されている。

【００５２】この第２実施の形態は、後述するように短絡補助第１回路８０ＡによりＵ相コイル、Ｖ相コイル及びＷ相コイルの短絡を図るようにしており、前記第１実施の形態で用いた第１、第２リレー６５，６６（短絡回路８０）を廃止したものになっている。この第２実施の形態では、例えば第２ＦＥＴ５４２に対する制御線９０が断線した場合、第１、第２トランジスタ７０，７１は、そのベース（Ｂ）に電圧が印加されないことから、動作しない。この際、サスペンションユニット２のストロークによりモータ３が発電機として動作し、Ｕ－Ｖ相間に逆起電圧が生じ、Ｕ相の電圧が高い場合は、第２ＦＥＴ５４２のドレイン〔Ｄ〕にＵ相の逆起電圧が加わる。

【００５３】そして、ダイオード６７及び抵抗６８を通して第２ＦＥＴ５４２のゲート〔Ｇ〕に電圧が印加され、第２ＦＥＴ５４２を導通（ＯＮ）させることができる。この結果、第２ＦＥＴ５４２のドレイン〔Ｄ〕側からソースへ電流が流れ、Ｖ相コイルに対応する第４ＦＥＴ５４４に内蔵されたフリーホイールダイオード９１を介してＶ相コイル及びＷ相コイルに電流が流れ（すなわち、Ｕ相コイル、Ｖ相コイル及びＷ相コイルが短絡された状態となり）、サスペンションユニット２は減衰力を発生することになる。

【００５４】なお、正常動作時にもダイオード６７を通じて逆起電圧が第２ＦＥＴ５４２のゲート〔Ｇ〕に印加されるが、第１、第２トランジスタ７０，７１が動作することから、抵抗６８の抵抗値を大きくすれば第２ＦＥＴ５４２のスイッチング動作には影響を与えない。すなわち、モータ３に接続される動力ケーブル８１が断線した場合、サスペンションユニット２がストロークしたことにより、モータ３が発電機として動作し、逆起電圧によって自動的に第２ＦＥＴ５４２が導通して（ＯＮして）各相のコイルが短絡され、電流が流れることにより、サスペンションユニット２は減衰力を発生することになる。

【００５５】この第２実施の形態では、ドライバ４の第２ＦＥＴ５４２のゲート制御信号が断線しても、モータ３の逆起電圧を利用し、第２ＦＥＴ５４２を導通する（ＯＮする）ことにより、断線時でも減衰力が発生することができる。なお、モータ３の逆起電圧を使用しているため、サスペンションユニット２がストロークしていない場合はもちろん、ストローク速度が低く、逆起電圧が低い場合も第２ＦＥＴ５４２を導通させる（ＯＮさせる）ことができない。このため、ストローク速度が低い場合は減衰力を発生することができないことになる。

【００５６】次に、本発明の第３実施の形態を図９及び図１０に基づいて説明する。第３実施の形態の電磁サスペンション装置は、図９及び図１０に示すように、第２実施の形態のＦＥＴゲート駆動用電源９２を廃止し、かつサスペンションユニット２のストローク速度が低く、逆起電圧が低い場合でも下側アームのＦＥＴの第２、第４、第６ＦＥＴ５４２，５４４，５４６（以下、便宜上、第２ＦＥＴ５４２を例にして説明する。）を導通でき（ＯＮすることができ）、ストローク速度が低い領域でも減衰力を発生できるようにしている。

【００５７】第３実施の形態は、第２実施の形態のＦＥＴ回路４９Ａに代えるＦＥＴ回路４９Ｂを有している。ＦＥＴ回路４９Ｂは、ＦＥＴ回路４９Ａの短絡補助第１回路８０Ａに代えて、短絡補助第２回路８０Ｂを有している。短絡補助第２回路８０Ｂは短絡補助第１回路８０Ａの第１、第２トランジスタ７０，７１に代えて第３、第４トランジスタ７２，７３を有している。第３、第４トランジスタ７２，７３の各エミッタは接続されており，この接続部は第２ＦＥＴ５４２のゲートに接続されている。第３、第４トランジスタ７２，７３の各ベースは接続されており，この接続部にはエミッタが接地されたｎｐｎ形の第５トランジスタ９５のコレクタが接続されている。第５トランジスタ９５のベース（Ｂ）には、制御線９０が接続されている。

【００５８】第３トランジスタ７２のコレクタと第２ＦＥＴ５４２のドレインとは、直列接続されたダイオード７４及び抵抗７５を介して接続されている。第３トランジスタ７２のコレクタとエミッタとは抵抗７８を介して接続されている。抵抗７８と抵抗７５の接続部分には、一端が接地されたコンデンサ７６の他端が接続されている。コンデンサ７６にはツェナーダイオード７７が並列に接続されている。また、第３トランジスタ７２のコレクタと第５トランジスタ９５のコレクタとは抵抗９６を介して接続されている。

【００５９】この第３実施の形態では、第２ＦＥＴ５４２のドレイン電圧が高いとき、すなわち、モータ３の逆起電圧により第２ＦＥＴ５４２のドレインに電圧が加わっているとき、または上アーム側の第１ＦＥＴ５４１がＯＮしているとき、ダイオード７４及び抵抗７５を通してコンデンサ７６に電荷が蓄えられる。この電圧は第２ＦＥＴ５４２のゲートを十分駆動できる電圧とし、ツェナーダイオード７７により一定電圧に保たれるようにする。

【００６０】コンデンサ７６に蓄えられた電圧は、ゲート駆動用の電源となり、第３、第４トランジスタ７２，７３により第２ＦＥＴ５４２のゲートを駆動する。ゲート制御信号は負論理となり、ゲート制御信号がローレベルの場合、第２ＦＥＴ５４２のゲートはＯＮし、ハイレベルのときＯＦＦとなる。ゲート信号が断線などにより発生しなくなると、コンデンサ７６に蓄えられた電圧が抵抗７８を介して第２ＦＥＴ５４２のゲートに印加さ

れ、第２ＦＥＴ５４２をＯＮし、減衰力を発生することになる。そして、この場合、仮にサスペンションユニット２のストローク速度が低く、逆起電圧が低い場合でも下側アームのＦＥＴの第２、第４、第６ＦＥＴ５４２，５４４，５４６（以下、便宜上、第２ＦＥＴ５４２を例にして説明する。）を導通でき（ＯＮすることができ）、ストローク速度が低い領域でも減衰力を発生できる。

【００６１】上記第１～第３実施の形態では、サスペンションユニット２が円筒形リニアモータ構造である場合を例にしたが、これに代えて、図１１に示すサスペンションユニット２Ａを用いてもよい。図１１に示すサスペンションユニット２Ａは、外筒部材２０Ａと、外筒部材２０Ａに一端側が挿入され他端側が外筒部材２０Ａから突出する筒状のロッド２１Ａと、ロッド２１Ａの一端側に固定されたボールナット１６５と、ボールナット１６５に螺合し、ベアリング１６６を介して外筒部材２０Ａに回動可能に支持されたボールねじ１６７とを備えている。サスペンションユニット２Ａは、さらに、ボールねじ１６７と同軸のシャフト１６８に固定された永久磁石２３Ａと、外筒部材２０Ａに固定されたコイル２２Ａと、コイル２２Ａ内に設けられた図示しないコア材とを備えている。外筒部材２０Ａの開口端には、環状の案内部材６９が装着され、案内部材１６９の内側にはロッド２１Ａに摺動してこのロッド２１Ａを案内する摺動部１７０が設けられている。

【００６２】このサスペンションユニット２Ａでは、コイル２２Ａへの通電によりコイル２２Ａと永久磁石２３Ａとの間に電磁力を発生し、永久磁石２３Ａ（シャフト６８）ひいてはボールねじ１６７が回転し、これによりボールナット１６５を介してロッド２１Ａが外筒部材２０Ａに対して軸方向に相対変位し、推進力を発生し、振動抑制効果を向上できる

また、車体の上下振動に伴いロッド２１Ａ及び外筒部材２０Ａが軸方向に相対的に変位すれば、軸方向の動きがボールナット１６５及びボールねじ１６７により回転運動に変換され、永久磁石２３Ａ（シャフト１６８）が回転しコイル２２Ａに起電力が発生し、ロッド２１Ａ及び外筒部材２０Ａの相対速度に応じた抵抗力、すなわち減衰力を発生することになる。

【００６３】上記第１ないし第３実施の形態では、無制御時にＵ相コイル、Ｖ相コイル及びＷ相コイルを短絡する場合を例にしたが、この短絡に際し、抵抗を挿入し、モータ３が発電機として動作した際に生じる電力を消費するようにしてもよい。

【００６４】

【発明の効果】請求項１に記載の発明によれば、ケーブル断線等サスペンションユニットへ供給される信号の異常時にコイル部材が閉ループを構成するように短絡回路を設けたので、サスペンションユニットのストロークによりコイル部材に生じる起電力によって減衰力を得ることができ、従来技術で故障時に起こり得た無減衰力状態を回避することができる。また、請求項２に記載の発明によれば、前記短絡回路をサスペンションユニットと一体に設けたことにより、制御手段やケーブルに故障があった場合も、短絡回路を作動させることができる。

【図面の簡単な説明】

【図１】本発明の第１実施の形態に係る電磁サスペンション装置を模式的に示す図である。

【図２】図１のサスペンションユニットを示す断面図である。

【図３】図１の制御装置を模式的に示すブロック図である。

【図４】図１のドライバを模式的に示すブロック図である。

【図５】図１の電磁サスペンション装置のリレーを用いた短絡回路を示す図である。

【図６】図１の電磁サスペンション装置の作用を示すためのフローチャートである。

【図７】本発明の第２実施の形態を模式的に示す図である。

【図８】図７の短絡補助第１回路を示す図である。

【図９】本発明の第３実施の形態を模式的に示す図である。

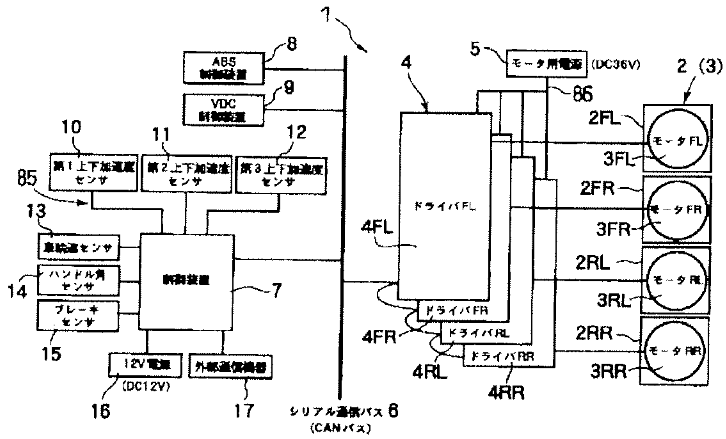
【図１０】図８の短絡補助第２回路を示す図である。

【図１１】図２のサスペンションユニットに代る他のサスペンションユニットを示す断面図である。

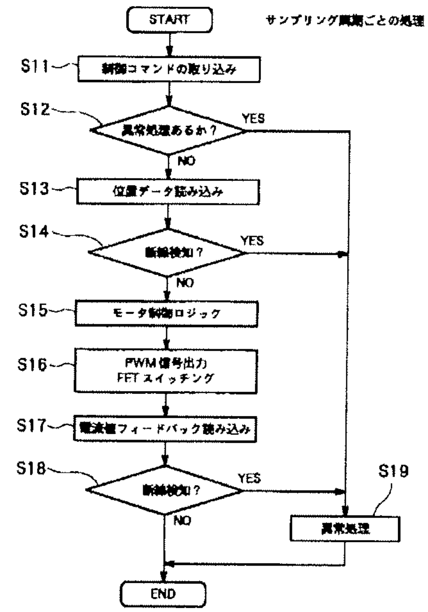
【符号の説明】

１　電磁サスペンション装置
２　サスペンションユニット
３　モータ
２２　コイル（コイル部材）
２３　永久磁石（磁石部材）
６５　第１リレー（短絡回路）
６６　第２リレー（短絡回路）

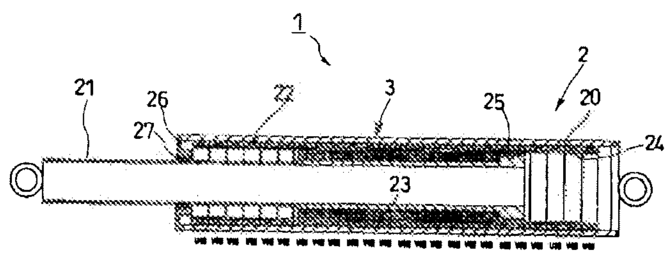
【図１】


1
ABS 制御装置
8
VDC 制御装置
9
10
11
12
第１上下加速度センサ
第２上下加速度センサ
第３上下加速度センサ
85
13
車輪速センサ
ハンドル角センサ
14
ブレーキセンサ
15
制御装置
7
12V電源 (DC12V)
外部通信機器
16
17
シリアル通信バス 6 (CANバス)
5
モータ用電源 (DC36V)
4
86
2 (3)
2FL
3FL
モータFL
ドライバFL
4FL
2FR
3FR
モータFR
2RL
3RL
モータRL
2RR
3RR
モータRR
ドライバFR
ドライバRL
ドライバRR
4FR
4RL
4RR

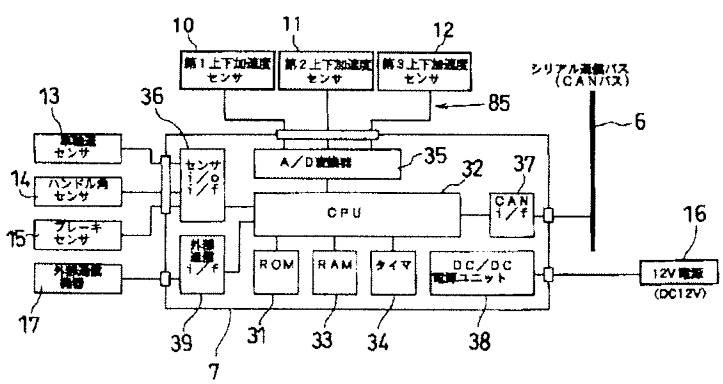
【図６】


START
サンプリング周期ごとの処理
S11
制御コマンドの取り込み
S12
異常処理あるか？
YES
NO
S13
位置データ読み込み
S14
断線検知？
YES
NO
S15
モータ制御ロジック
S16
PWM信号出力
FETスイッチング
S17
電流値フィードバック読み込み
S18
断線検知？
YES
NO
S19
異常処理
END

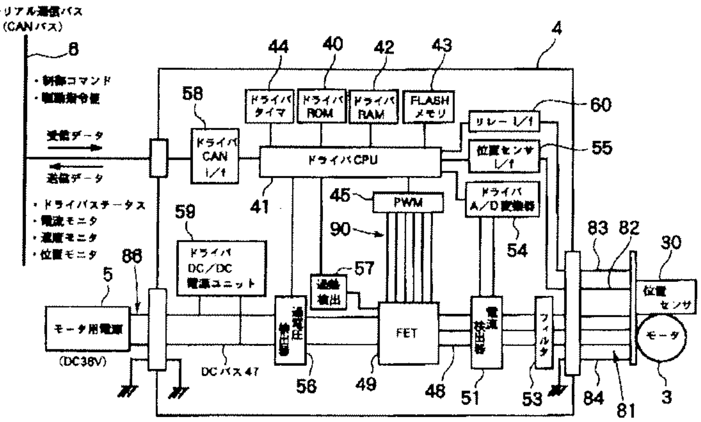
【図２】


1
2
21
26
22
3
25
20
27
24
23

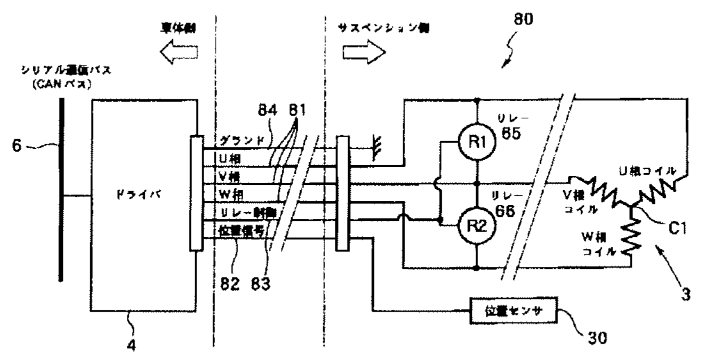
【図３】


10
11
12
第１上下加速度センサ
第２上下加速度センサ
第３上下加速度センサ
85
シリアル通信バス (CANバス)
6
13
36
車輪速センサ
14
ハンドル角センサ
15
ブレーキセンサ
センサi/f
A/D変換器
35
32
37
CPU
CAN i/f
外部通信機器
外部通信i/f
ROM
RAM
タイマ
DC/DC電源ユニット
16
12V電源 (DC12V)
17
39
31
33
34
38
7

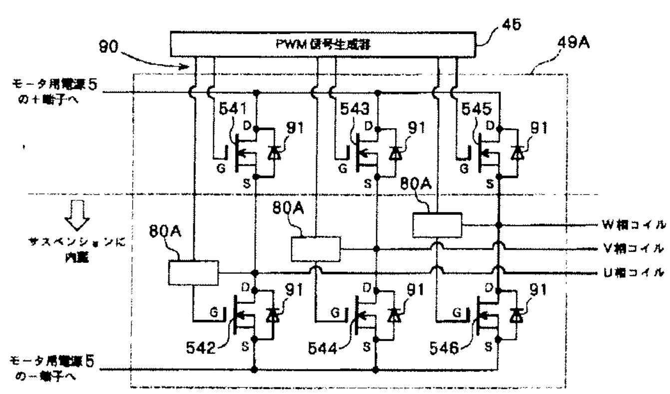
【図４】


シリアル通信バス
(CANバス)
・制御コマンド
・駆動指令値
受信データ
送信データ
・ドライバステータス
・電流モニタ
・速度モニタ
・位置モニタ
ドライバタイマ
ドライバROM
ドライバRAM
FLASHメモリ
リレーI/f
位置センサI/f
ドライバCAN I/f
ドライバCPU
PWM
ドライバA/D変換器
ドライバDC/DC電源ユニット
過熱検出
FET
フィルタ
位置センサ
モータ
モータ用電源
(DC38V)
DCバス47
4
6
44
40
42
43
60
55
58
41
45
90
57
59
54
83
82
30
5
86
56
49
48
51
53
84
81
3

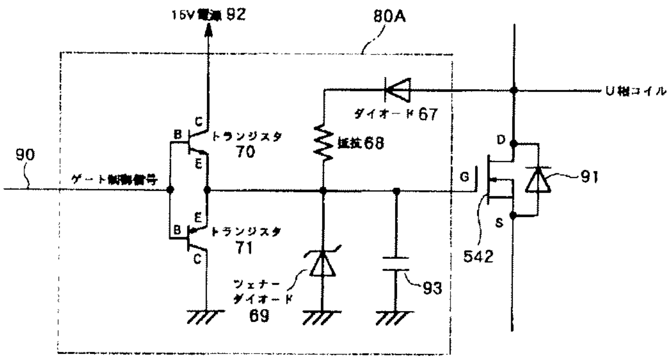
【図５】


車体側
サスペンション側
80
シリアル通信バス
(CANバス)
6
ドライバ
グランド
U相
V相
W相
リレー制御
位置信号
84
81
82
83
4
R1
R2
リレー
65
66
U相コイル
V相コイル
W相コイル
C1
3
位置センサ
30

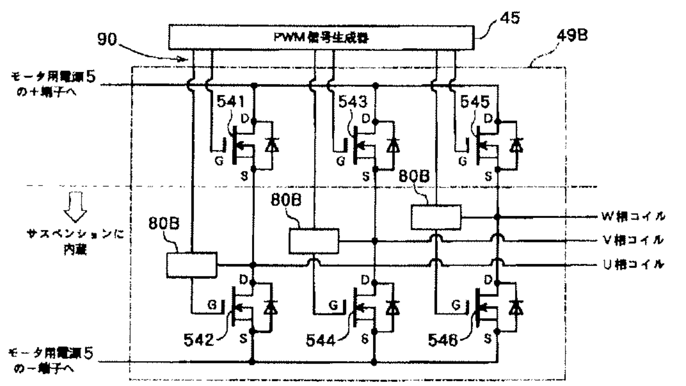
【図７】


PWM信号生成器
45
90
49A
モータ用電源5
の＋端子へ
541
543
545
91
D
G
S
80A
サスペンションに
内蔵
W相コイル
V相コイル
U相コイル
542
544
546
モータ用電源5
の－端子へ

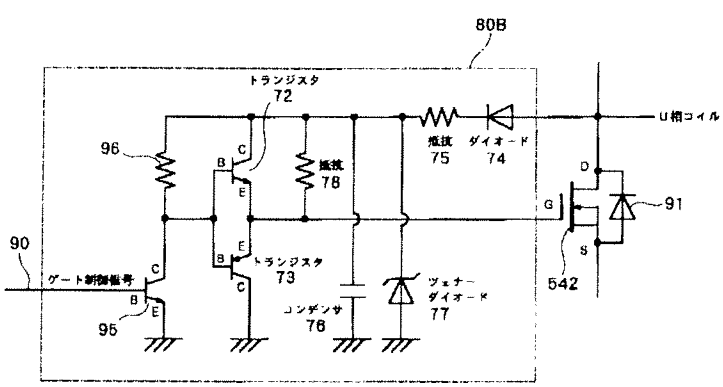
【図８】


15V電源 92
80A
U相コイル
ダイオード 67
抵抗 68
トランジスタ
70
90
ゲート制御信号
91
トランジスタ
71
542
ツェナー
ダイオード
69
93

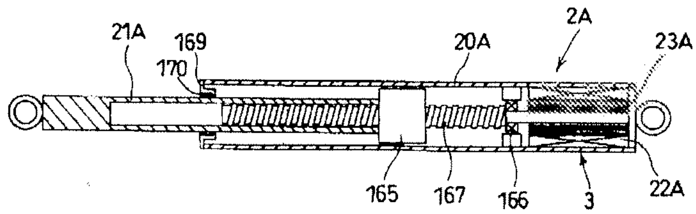
【図９】


PWM信号生成器
45
49B
90
モータ用電源５
の＋端子へ
541
543
545
80B
80B
80B
W相コイル
V相コイル
U相コイル
サスペンションに
内蔵
542
544
546
モータ用電源５
の－端子へ

【図１０】


80B
トランジスタ
72
U相コイル
96
抵抗
75
ダイオード
74
抵抗
78
91
90
ゲート制御信号
トランジスタ
73
コンデンサ
76
ツェナー
ダイオード
77
95
542

【図１１】



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3J048 AA06 AB11 AC08 AD01 DA01
EA16
5H223 AA10 BB08 CC01 CC08 DD01
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B60G 17/00		B60G 17/00	3J048
F16F 15/03		F16F 15/03	B 5H223

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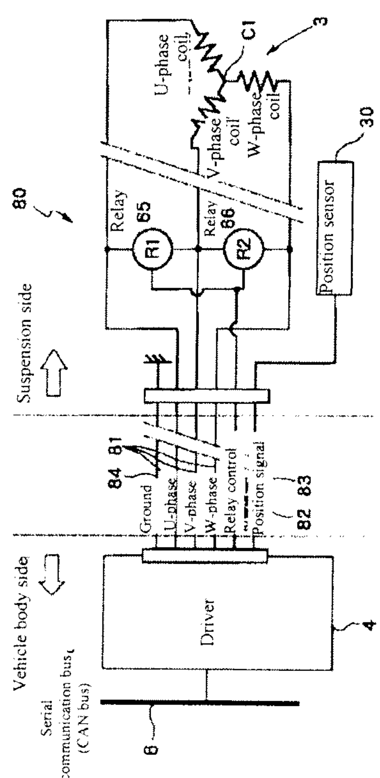
Continued on last page

(54) (TITLE OF THE INVENTION) Electromagnetic suspension apparatus

(57) (ABSTRACT)

(PROBLEM) To provide an electromagnetic suspension apparatus capable of generating a damping force with a motor when control of the electromagnetic suspension apparatus is impossible due to an open circuit in a cable, etc. (during uncontrolled operation).

(MEANS FOR SOLVING) If an open circuit in power cable 81 is detected, a relay control signal is turned off, closing first and second relays 65 and 66 and shorting a U-phase coil, V-phase coil, and W-phase coil via first and second relays 65 and 66. Thus, when the suspension unit makes a stroke, a motor 3 provided on the suspension unit acts as an electric generator, generating resistance, in other words a damping force, of a magnitude substantially proportional to the stroke speed.



(SCOPE OF PATENT CLAIMS)

(CLAIM 1) An electromagnetic suspension apparatus comprising a suspension unit, which is provided with a pair of displacement members capable of relative displacement,

with a magnet member being provided on one of said pair of displacement members and a coil member which together with said magnet member constitutes a motor being provided on the other displacement member, and which obtains propulsive force through electromagnetic force generated between said coil member and said magnet member due to electrification of said coil member and obtains damping force through electromotive force generated in said coil member due to relative displacement of said coil member and said magnet member; and a control means which controls electrification of said suspension unit, said electromagnetic suspension apparatus being characterized in that it is provided with an error detection means which detects errors in the signal provided from the control means to the suspension unit, and a shorting circuit which causes the coil member to form a closed loop.

(CLAIM 2) The electromagnetic suspension apparatus described in claim 1, characterized in that said control means is provided on the vehicle body side, said control means being connected to said suspension unit with a cable, and said shorting circuit is provided integrally with the suspension unit.

(DETAILED DESCRIPTION OF THE INVENTION)

(0001)

(TECHNICAL FIELD OF THE INVENTION) The present invention concerns actuators and dampers for vibration suppression using electromagnetic force, and particularly relates to electromagnetic suspension apparatus suitable for use in automobiles, motorcycles, rail cars, structures, buildings, etc.

(0002)

(PRIOR ART) Examples of conventional electromagnetic suspension apparatus include electromagnetic suspension apparatus which, instead of a damping force generating mechanism such as the orifice of a hydraulic damper, employ a linear motor, or a rotary motor and a linear-rotary motion conversion mechanism which converts the rotary motion of the rotor of the rotary motor to linear motion. Electrifying such an electromagnetic suspension apparatus causes displacement of the movable parts and makes the motor actively operate as a motor proper (an actuator), while using the motor as an electric generator (passively) generates damping force.

(0003) When the motor is used as an electric generator, the resistance, in other words the damping force, generated by the motor (electric generator) is proportional to the magnitude of the current flowing to the coil, so the damping force can be made variable by adjusting the magnitude of the current flowing to the coil. Adjustment of the current flowing to the coil can be easily implemented, for instance, by providing a variable resistor within the circuit, or providing a switch which turns the circuit on and off and controlling the on-off time ratio of the switch.

(0004) Thus, variably controlling the damping force of an electromagnetic suspension apparatus according to the stroke speed and stroke position, or variably controlling it in real time to suppress vibration of the control target so as to provide as a so-called semi-active damper is relatively easy. Furthermore, when it is configured as a semi-active damper in this manner (used as an electric generator), there is no need to provide electric energy to the electromagnetic suspension apparatus, making it possible to greatly reduce power consumption.

(0005) Furthermore, if an electromagnetic suspension apparatus is provided with electrical energy and used as a motor, it is easy to generate an arbitrary force, which makes it possible to apply force so as to increase the damping force, or generate an arbitrary control force to operate the apparatus as an active suspension and increase the vibration suppression effect, and methods of increasing the vibration suppression effect in this manner have been proposed as well. Direct current motors and synchronous motors are used as motors in the above-described electromagnetic suspension apparatus.

(0006)

(PROBLEM TO BE SOLVED BY THE INVENTION) The drive system, excluding the sensor section, in the aforementioned electromagnetic suspension apparatus mainly consists of a power supply, a motor driving circuit and a motor which generates propulsive force and damping force. Currently, a power supply and motor are difficult to integrate and are separated, so a cable joining the power supply and motor to each other becomes necessary. Normally, the connections between power supply unit and motor driving circuit and between motor driving circuit and motor are made with cables. However, if these cables become open-circuited or if an open circuit occurs within the motor driving circuit (in case of uncontrolled operation), there is the problem that the motor is not only unable to generate propulsive force but also cannot generate damping force, so the motor assumes an undamped state. Furthermore, there is the problem that if the ignition key is not turned on, or in cases of a dead battery or the like (in case of uncontrolled operation), no power is supplied to the motor driving circuit or motor, and the motor assumes an undamped state, just as described above.

(0007) The present invention was made in view of the circumstances described above, its object being to provide an electromagnetic suspension apparatus capable of generating a damping force with the motor when control of the electromagnetic suspension apparatus is impossible due to an open circuit in a cable or the like (during uncontrolled operation).

(0008)

(MEANS FOR SOLVING THE PROBLEM) The invention described in claim 1 is an electromagnetic suspension apparatus comprising a suspension unit, which is provided with a pair of displacement members capable of relative displacement, with a magnet member being provided on one of said pair of displacement members and a coil member which together with said magnet member constitutes a motor being provided on the other displacement member, and which obtains propulsive force through electromagnetic force generated between said coil member and said magnet member due to electrification of said coil member and obtains damping force through electromotive force generated in said coil member due to relative displacement of said coil member and said magnet member; and a control means which controls electrification of said suspension unit, said electromagnetic suspension apparatus being characterized in that it is provided with an error detection means which detects errors in the signal provided from the control means to the suspension unit, and a shorting circuit which causes the coil member to form a closed loop. The invention described in claim 2 is characterized in that, in the configuration described in claim 1, said control

means is provided on the vehicle body side, said control means being connected to said suspension unit with a cable, and said shorting circuit is provided integrally with the suspension unit.

(0009)

(MODES OF EMBODIMENT OF THE INVENTION) The electromagnetic suspension apparatus of a first mode of embodiment of the present invention will be described based on Figures 1 through 6.

(0010) In Figure 1 and Figure 2, electromagnetic suspension apparatus 1 is used in automobiles, and has four suspension units mounted between each wheel side member and the vehicle body. The suspension units corresponding to the right front wheel side member, left front wheel side member, right rear wheel side member, and left rear wheel side member will be referred to respectively as the right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side suspension units 2FR, 2FL, 2RR, and 2RL. The right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side suspension units 2FR, 2FL, 2RR, and 2RL are each provided with a three-phase synchronous motor (respectively referred to as right front wheel side, left front wheel side, right rear wheel side and left rear wheel side motors 3FR, 3FL, 3RR and 3RL) comprising a star-connected U-phase coil, V-phase coil and W-phase coil (references omitted). The right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side suspension units 2FR, 2FL, 2RR and 2RL have the same configuration, and may be referred to below collectively as suspension unit 2. Furthermore, the right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side motors 3FR, 3FL, 3RR, and 3RL may be similarly referred to collectively as motor 3.

(0011) A driver is connected to the right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side motors 3FR, 3FL, 3RR and 3RL (referred to respectively as right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side drivers 4FR, 4FL, 4RR and 4RL) to drive the motors 3. The right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side drivers 4FR, 4FL, 4RR and 4RL have the same configuration, and may be referred to hereinafter collectively as driver 4. A driver 4 is provided on the suspension tower part corresponding to each wheel. The drivers 4 are connected to a DC 36V motor power supply 5.

(0012) A control device 7 (vibration and attitude control means) is connected as a control means to the driver 4 via serial communication bus 6, and operational instructions from the control device 7 to the driver 4 and various types of feedback from the driver 4 to the control device 7, etc. is all performed through serial communication (for example, serial communication based on the CAN (Controller Area Network) specification). In the serial communication protocol, a "command" from control device 7 and a "response" from driver 4 form a set, and a "command" and "response" are exchanged every set time interval (e.g. 5 ms) (in every control period of the control device 7).

(0013) Furthermore, for example, if no "command" from the control device 7 to the driver 4 is transmitted for more than a set period of time (e.g. 20 ms), or if no "response" is transmitted from the driver 4 to the control device 7 for more than a set period of time (e.g. 20 ms), a system error is deemed to exist in the control device 7 or driver 4, and error handling such as "disconnection of motor power supply 5," "error display," etc. is carried out. An ABS (Anti-lock Brake System) control device 8 and VDC (Vehicle Dynamics Control) control device 9 are connected to the serial communication bus 6. The ABS control device 8 and VDC control device 9 ensure vehicle travel stability. The electromagnetic suspension apparatus 1, ABS control device 8, and VDC control device 9 are capable of coordinated operation.

(0014) Control device 7 performs electrification of motor 7 and thus control of generation of propulsive force by motor 3, as well as control of damping force through electromotive force generation (use as an electric generator) of the motor 3. Three vertical acceleration sensors (hereinafter referred to as first, second and third vertical acceleration sensors) 10, 11, and 12 which detect vertical vibration of the vehicle body, wheel speed sensor 13, steering wheel angle sensor 14, brake sensor 15, and DC 12V power supply (hereinafter referred to as 12V power supply) 16 are connected to control device 7. An external communication device 17 used for system diagnosis and the like is also connected to the control device 7. The first vertical acceleration sensor 10 is provided on the right front wheel suspension tower part, the second vertical acceleration sensor 11 is provided on the left front wheel suspension tower part, and the third vertical acceleration sensor 12 is provided in the rear trunk part.

(0015) Suspension unit 2, as shown in Figure 2, comprises an outer cylinder member 20 (one of the pair of displacement members) retained on the vehicle body side of the vehicle, and a rod 21 (the other of the pair of displacement members), whereof one end fits into the outer cylinder member 20 in a way that allows relative displacement and whereof the other end is supported on the vehicle axle side of the vehicle. A plurality of coils 22 (coil member) is provided over a predetermined length in the axial direction so as to lie between the outer cylinder member 20 and rod 21, and a permanent magnet (magnet member) 23 is provided over a predetermined length in the axial direction on the outside of the rod 21.

(0016) A cylindrical guide member (hereinafter referred to as first guide member) 24 is provided between the coils 22 and the rod 21 (permanent magnet 23), and a sliding part (hereinafter referred to as first sliding part) 25 which slides over the first guide member 24 is provided on one end of the rod 21. An annular guide member (hereinafter referred to as second guide member) 26 is installed on the open end of the outer cylinder member 20. A sliding part (hereinafter referred to as second sliding part) 27 which slides over the rod 21 and guides the movement thereof is provided on the inside of the second guide member 26. Rod 21 is slidably supported in relation to outer cylinder member 20 by first sliding part 25 and second sliding part 27.

(0017) The coils 22 are configured with a U-phase, V-phase, and W-phase alternating in the axial direction. Permanent magnet 23 is configured with an N pole and S pole alternating in the axial direction. When the coils 22 are electrified, thrust is generated in the axial direction between the coils 22 and the permanent magnet 23, and the outer cylinder member 20 and rod 21 undergo a relative displacement (stroke). The direction of the thrust is determined based on the direction of electrification of the coils 22. In the present mode of embodiment, the aforementioned motor 3 comprises the coils 22, permanent magnet 23, the outer cylinder member 20 which supports coils 22, the rod 21 which supports the permanent magnet 23, etc. Furthermore, when the outer cylinder member 20 and rod 21, and thus the coils 22 and permanent magnet 23, undergo relative displacement, electromotive force is generated in the coils 22 and the motor 3 acts as an electric generator. Motor 3 or suspension unit 2 is provided with a position sensor 30 (see Figure 4), allowing the detection of relative displacement (stroke) of coils 22 and permanent magnet 23, or of the outer cylinder member 20 and rod 21.

(0018) Control device 7 comprises a ROM 31 which stores fixed data such as constants and the control program of the electromagnetic suspension apparatus 1; a CPU 32 which executes the control program and exercises overall control of the electromagnetic suspension apparatus 1; RAM 33, which temporarily stores the computations results of CPU 32 and the like; and timer 34, which generates the sampling times, etc. Control device 7 additionally comprises an A/D converter 35 which converts the analog signals from the first, second, and third vertical acceleration sensors 10, 11, and 12 to digital signals; a sensor i/o interface (sensor i/o i/f) 36 which processes signals from wheel speed sensor 13, steering wheel angel sensor 14, and brake sensor 15; a CAN interface 37 for serial communication with the drivers 4, etc.; DC/DC power supply unit 38 which provides conversion from 12 V power supply 16 to 5 V, 3.3 V or other voltages required by the CPU 32, etc.; and external communication device interface 39, which exchanges signals with external communication device 17. In the present mode of embodiment, the power consumption limitation means is constituted as a sequence within the control program of control device 7 stored in ROM 31.

(0019) In the present electromagnetic suspension apparatus 1, among the states of the vehicle, vertical vibration of the vehicle body is detected by the first, second, and third vertical acceleration sensors, as discussed above. Furthermore, the magnitude of rolling and pitching of the vehicle body is evaluated on the basis of the detection signal of the aforementioned position sensor 30, or the stroke of the suspension unit 2 of each wheel. Furthermore, detection of the state of the vehicle is not limited to the aforementioned first, second, and third vertical acceleration sensors 10, 11, and 12 and position sensor 30, and is also performed using wheel speed sensor 13, steering wheel angle sensor 14, and brake sensor 15.

(0020) Based on the signals from the aforementioned first, second, and third vertical acceleration sensors 10, 11, and 12, the position sensor 30, the wheel speed sensor 13, the steering wheel angle sensor 14, and the brake sensor 15, the control device 7 determines the magnitude of control of the suspension unit 2 of each wheel and sends drive signals to the motors 3 of the drivers 4 so as to suppress vehicle vibration, attitude change, and unstable vehicle behavior, and to make the vehicle more stable in response to the vehicle speed and the driver's manipulation of the steering wheel, accelerator, and brake.

(0021) The driver 4, as shown in Figure 4, comprises a ROM (hereinafter referred to as driver ROM) 40 which stores fixed data such as constants and a motor drive control program; a CPU (hereinafter referred to as driver CPU) 41 which executes said motor drive control program, controls communication with the control device 7 and exercises control over the drivers 4; RAM (hereinafter referred to as driver RAM) 42 which temporarily stores the computation results, etc. of driver CPU 41; a flash memory 43 which stores rewritable parameters, etc. and is treated as specific to the vehicle and driver, etc.; and a timer (hereinafter referred to as driver timer) 44 which generates the sampling times, etc.

(0022) Driver 4 further comprises a PWM signal generator 45 for driving of motor 3; FET 49 which is connected to motor power supply 5 (DC 36 V) via DC bus 47, converts the current from the motor power supply 5 to three-phase current for use for driving the motor 3, and outputs this current through motor connection wire 48 to the motor 3; a current detector 51 which is provided on the motor connection wire 48 and detects the drive current of the motor 3; and a line filter 53 provided on the output side of the motor connection wire 48. Furthermore, driver 4 comprises an A/D converter (hereinafter referred to as driver A/D converter) 54 which converts analog signals from current detector 51 to digital signals; a position sensor interface (position sensor i/f) 55 which converts signals from the aforementioned position sensor 30 to digital signals and inputs them into driver CPU 41; and a relay interface (relay i/f) 60 which inputs relay control signals from driver CPU 41 into first and second relays 65 and 66.

(0023) First and second relays 65 and 66 comprise an excitation coil (not illustrated) which allows input of relay control signals; and a normally closed contact point (not illustrated) which opens and closes in response to the relay control signal inputted into the excitation coil, and are fashioned as normally closed relays. When the relay control signal of the excitation coil is on, the aforementioned contact point (and thus the first and second relays 65 and 66) opens (turns off). In this mode of embodiment, upon turning on the power supply (turning on the ignition switch) the relay control signal turns on and the first and second relays 65, 66 open (turn off); normally, this state (the state where the first and second relays 65, 66 are open (off)) is maintained. As will be discussed later, if a fault such an open circuit in a cable occurs (in case of uncontrolled operation), the relay control signal is turned off and the first and second relays 65, 66 are closed (turned on).

(0024) The driver 4 additionally comprises an overvoltage detector 56 which monitors the voltage of DC bus 47; an overheating detector 57 which detects overheating of FET 49; CAN i/f (hereinafter referred to as driver CAN interface) 58, which is an interface for serial communication with the control device 7; and a DC/DC power supply unit (hereinafter referred to as driver DC/DC power supply unit) 59 which performs conversion from motor power supply 5 to 5 V, 12 V, 15 V, or other voltages required for operation of the driver CPU 41 and other parts.

(0025) Upon receiving a control command such as "servo ON" and the control magnitude, etc. for actually driving the motor 3 from the control device 7 through serial communication bus 6, in every sampling time period (control period of driver 4), the driver 4 acquires operating speed of the motor 3 and the phase angle (electrical angle) between the magnetic circuit formed by the permanent magnet 23 and the U-phase, V-phase, and W-phase coils 22 within the motor 3 based on the signal of the position sensor 30, and the current level and voltage level of coils 22 based on the signal from the current detector 51, and regulates the PWM signal generator 45 so as to obtain motor operation according to the motor driving instruction from the control device 7. The aforementioned control period of the driver 4 is set at, for example, 250 μs, being substantially shorter than the control period of the control device 7 (e.g. 5 ms).

(0026) In this electromagnetic suspension apparatus 1, when the rod 21 and outer cylinder member 20 undergo relative displacement due to vertical vibration of the vehicle body, electromotive force is generated in the coils 22. Namely, the motor 3 acts as an electric generator, and current flows through the coils 22, as a result of which, the suspension unit 2 (motor 3) generates resistance, i.e. damping force, according to the relative speed of the rod 21 and outer cylinder member 20. Furthermore, in accordance with the relative positional relationship (electrical angle) of the rod 21 and outer cylinder member 20, and thus the vertical vibration state of the vehicle body, if current is supplied to the coils 22, the motor 3 will act as a motor proper (actuator) and produce propulsive force, allowing the vibration suppressing effect of the suspension unit 2 to be improved.

(0027) Figure 5 illustrates a circuit (shorting circuit) 80 which shorts the coils 22 in case of open circuit in a cable. The shorting circuit 80 comprises the aforementioned first relay 65 interposed between one end of the U-phase coil (the terminal part on the opposite side of the common contact terminal C1 of the U-phase coil, V-phase coil, and W-phase coil) and one end of the V-phase coil (the terminal part on the opposite side of the common contact terminal C1), and the aforementioned second relay 66 interposed between one end of the V-phase coil and one end of the W-phase coil (the terminal part on the opposite side of the common contact terminal C1), and is able to short the U-phase coil, V-phase coil and W-phase coil across the first and second relays 65 and 66, as discussed below. The shorting circuit 80 is provided in the suspension unit 2.

(0028) The suspension unit 2 (motor 3) and the driver 4 mounted on the vehicle body side are connected via power cable 81 that connects to the U-phase coil, V-phase coil, and W-phase coil of the motor 3; position signal cable 82 that extends from the position sensor 30; a cable (relay control cable) 83 for control of the first and second relays 65 and 66; and ground cable 84. Furthermore, first, second, and third vertical acceleration sensors 10, 11, and 12 and control device 7 are connected via acceleration signal cable 85. In this mode of embodiment, if any of the aforementioned cables (power cable 81, position signal cable 82, relay control cable 83, and acceleration signal cable 85) is open-circuited, or if a fault occurs such that no power is supplied from the battery (12 V power supply 16, motor power supply 5), etc. (such cases may be referred to hereinafter as power supply interruption) (in case of uncontrolled operation), the driver 4 turns off the relay control signal outputted to the first and second relays 65, 66.

(0029) As indicated above, the first and second relays 65 and 66 are normally closed relays, and the relay control signal from the driver 4 is normally turned on and outputted to keep the first and second relays 65 and 66 in an open (off) state. In this normal state, the first and second relays 65 and 66 are kept open, so the U-phase coil, V-phase coil, and W-phase coil are not shorted, and the motor 3 is normally controlled and is able to generate propulsive force (act as a motor proper) and damping force (act as an electric generator).

(0030) If no relay control signal is outputted from the driver 4 (if the relay control signal is off), the first and second relays 65 and 66 assume a closed (on) state (the same state as normally), and the U-phase coil, V-phase coil, and W-phase coil become shorted due to the closure (turning on) of the first and second relays 65 and 66. In other words, in case of uncontrolled operation as described above (open-circuiting of one of the aforementioned cables or power supply interruption), the driver 4 turns off the relay control signal outputted to the first and second relays 65 and 66, and the U-phase coil, V-phase coil, and W-phase coil assume a shorted state.

(0031) If the U-phase coil, V-phase coil, and W-phase coil are shorted, when the suspension unit 2 makes a stroke, the motor 3 acts as an electric generator and generates resistance, in other words damping force, of a magnitude substantially proportional to the stroke speed. Below, examples of specific open circuit locations will be used to explain the method of open circuit detection (error detection means) and the control method in such cases. Detection of open circuit in the power cable 81 (the cable between the driver 4 and motor 3) is performed as follows.

(0032) Namely, a current detector 51 is incorporated into the driver 4, which checks if the current level instructed by the driver CPU 41 is being accurately outputted to the U-phase coil, V-phase coil, and W-phase coil by detecting the outputted current, and feeds back the detected value to the driver CPU 41. If the

power cable 81 is open-circuited, the current level fed back to the driver CPU 41 will present an abnormal value (a value indicating zero or very low current level). The driver CPU 41 uses this fact to determine the presence or absence of open circuit in the power cable 81.

(0033) If the driver CPU 41 determines that an open circuit is present in the power cable 81 (if an open circuit has been detected in the power cable 81), it turns off the relay control signal, closing the first and second relays 65 and 66 and shorting the U-phase coil, V-phase coil, and W-phase coil through the first and second relays 65 and 66, and also stops the motor control and notifies the control device 7 about the open circuit detection.

(0034) Next, determination of open circuit in the position signal cable 82 is performed as follows. If the position sensor 30 is a sensor of the type that constantly outputs a signal (e.g. the signal varies between 1 and 5 V), the presence of an open circuit can be determined if no signal is being outputted. Furthermore, for instance, in the case of a 0–5 V A, B phase pulse position sensor or the like, or a sensor which has states in which no output signal is outputted, the determination of open circuit in the position signal cable 82 or failure of position sensor 30 can be determined if the output of the position sensor is 0 V or does not change despite the fact that its output should change based on the output from the vertical acceleration sensor, etc. connected to the control device 7. If open circuit in the position signal cable 82 is detected, the control device 7 issues a notification of motor control stop to the driver 4. The driver CPU 41 then performs shorting of the U-phase coil, V-phase coil, and W-phase coil, stoppage of motor control and notification of the control device 7 regarding open circuit detection, in the same manner as described above.

(0035) Open circuit in the relay control cable 83 is detected as follows. Here, in order to open (turn off) the first and second relays 65 and 66, it is necessary to pass an excitation current (a relay control signal whereof the content (signal level) is ON) through the relay control cable 83 and excite the excitation coils contained in the first and second relays 65 and 66. Open circuit in the relay control cable 83 is normally detected by monitoring the excitation current (relay control signal) by means of the relay i/f 60 inside driver 4. If open circuit in the relay control cable 83 is detected, no signal is supplied to the first and second relays 65 and 66, so these relays automatically close (return to their normal state), shorting the U-phase coil, V-phase coil, and W-phase coil. Furthermore, the driver CPU 41 turns off the relay control signal, stops motor control, and notifies the control device 7 about the open circuit detection. Here, the reason for turning off the relay control signal is that, while there would be no problem in cases of complete open circuit in the relay control cable, in cases of repeated open circuit followed by reconnection and open circuit, the first and second relays 65 and 66 will repeatedly open and close, and in order to prevent this, it is necessary to leave the relay control signal off.

(0036) Furthermore, open circuit in the acceleration signal cable 85 is detected as follows. In this mode of embodiment, the acceleration signal from the first, second, and third vertical acceleration sensors 10, 11, and 12 is set for instance to a signal output of 1 to 5 V, centered on 3 V, and when no signal is outputted from the first, second, and third vertical acceleration sensors 10, 11, and 12 (for example, when the output signal of the first, second, and third vertical acceleration sensors 10, 11, and 12 is 0 V), it is stipulated that an open circuit can be determined to exist in the acceleration signal cable 85. The driver CPU 41 performs detection of open circuit in the acceleration signal cable 85 based on the acceleration signals from the first, second, and third vertical acceleration sensors 10, 11, and 12. If an open circuit is detected, the driver CPU 41 performs shorting of the U-phase coil, V-phase coil, and W-phase coil, stoppage of motor control, and notification of the control device 7 regarding open circuit detection, in the same manner as described above.

(0037) Furthermore, if the control device 7 or driver 4 ceases to operate normally due to runaway operation or the like, the driver CPU 41 stops supplying power to the motor 3, closes the first and second relays 65 and 66, and puts the U-phase coil, V-phase coil, and W-phase coil into a shorted state. To determine the presence or absence of runaway operation, for example, the CPU is made to periodically access the relay i/f and PWM signal generator, and the relay i/f and PWM signal generator are provided with a function of determining the presence or absence of this periodic access and stopping the output in case of absence of the periodic access. As a result, in case of runaway operation, periodic access ceases to be performed, and thus the output from the relay i/f and PWM signal generator stops, supply of power to the motor 3 is discontinued, and the U-phase coil, V-phase coil, and W-phase coil are placed into a shorted state. Furthermore, if an open circuit occurs in the power supply cable 86 connecting the motor power supply 5 and the driver 4, and supply of power to the driver 4 stops, the relay control signal is turned off, the first and second relays 65 and 66 close, and the U-phase coil, V-phase coil, and W-phase coil are placed into a shorted state.

(0038) Furthermore, if an abnormal operation such as closing (turning on) of the first and second relays 65 and 66 due to some sort of factor occurs during normal operation of the system, a shorted loop (closed circuit) is formed before the U-phase coil, V-phase coil, and W-phase coil, and current ceases to be supplied from the driver 4 to the U-phase coil, V-phase coil, and W-phase coil. In such cases, excess current corresponding to the removed resistance of the coils 22 flows through the power cable 81, and current level feedback anomalies (excess current levels) are detected by current detector 51, so the driver CPU 41 detects errors in the first and second relays 65 and 66.

(0039) If an error is detected in the first and second relays 65 and 66, the driver CPU 41 performs shorting of the U-phase coil, V-phase coil, and W-phase coil, and stoppage of motor control and notification of the control device 7 regarding open circuit detection, in the same manner as described above.

(0040) The above operation will be summarized based on the flow chart of Figure 6. Driver CPU 41 accepts a control command from control device 7 (step S11) and determines if there is an error handling request from the control device 7 (step S12). If the decision in step S12 is No (if error handling is not necessary), the driver CPU 41 reads position data from position sensor 30 for control of motor 3 (step S13).
(0041) Based on the reading of position data in step S13, the presence or absence of open circuit in position signal cable 82 is determined (step S14). In the next step 15, motor control logic is executed, the positional relationship of the magnet 23 and the coils 22 of the motor 3 is ascertained based on position data, and the current levels, etc. of the U-phase coil, V-phase coil, and W-phase coil are ascertained based on current level feedback (before 1 sampling), and the control magnitude for the motor 3 is determined based on the required torque and speed of the motor 3, etc.
(0042) Next, FET 49 is switched via the PWM signal generator 45 to adjust the voltage impressed on the U-phase coil, V-phase coil, and W-phase coil and controls the motor 3 to generate the prescribed torque and attain the prescribed speed (step S16). Subsequently, current level feedback of the U-phase coil, V-phase coil, and W-phase coil is received by current detector 51 (step S17) and the presence/absence of open circuit is determined (step S18).
(0043) If the decision in step S12 is Yes (error handling is required), or if the decision in step S14 is Yes (open circuit is present), power to the motor 3 is cut, and error handling such as shorting of the first and second relays 65 and 66 and transmission of error handling status to the control device 7 is performed (step S19).
(0044) As discussed above, the suspension unit 2 is able to generate damping force even during so-called uncontrolled operation, such as in cases of power supply interruption, open circuit in a cable, dead battery (power supply interruption), runaway operation of the control device 7 and driver 4, or turning off of the ignition switch, thereby greatly improving safety.
(0045) If the type of first and second relays 65 and 66 selected is one which allows passing large currents, the risk of breakdown will be reduced. By using a relay type that allows passing of large currents for the first and second relays 65 and 66, the suspension unit will be able to generate stable damping force for a long time even during uncontrolled operation, further improving safety.
(0046) Next, a second mode of embodiment of the present invention will be described based on Figure 7 and Figure 8. The electromagnetic suspension device of the second mode of embodiment, as shown in Figure 7 and Figure 8, has an FET circuit 49A instead of the aforementioned FET 49. FET circuit 49A has six FETs (hereinafter referred to as first through sixth FETs) 541 through 546. The source (S) of the first FET 541 is connected to the drain (D) of the second FET 542, and the connection area thereof is connected to the U-phase coil. The source (S) of the third FET 543 is connected to the drain (D) of the fourth FET 544, and the connection area thereof is connected to the V-phase coil. The source (S) of the fifth FET 545 is connected to the drain (D) of the sixth FET 546, and the connection area thereof is connected to the W-phase coil.
(0047) Six control wires 90 extend from the PWM signal generator 45 to FET circuit 49A, three of which are connected to the gates (G) of the first, third, and fifth FETs 541, 543, and 545 (which may be referred to hereinafter as upper arm FETs). The other three signal wires 90 of the aforementioned six control wires 90 are connected to the gates (G) of the second, fourth, and sixths FETs 542, 544, and 546 via a shorting auxiliary circuit (hereinafter referred to as first shorting auxiliary circuit) 80A. In this second mode of embodiment, the first shorting auxiliary circuit 80A and the second, fourth and sixths FETs 542, 544, and 546 form the shorting circuit.
(0048) The first FET 541 comprises a freewheeling diode 91 which connects the source (S) and drain (D) and permits electricity to pass through the freewheeling diode 91 from the source (S) to the drain (D). A freewheeling diode is connected between the source and drain of the second through sixths FETs 542 through 546 as well, just as in the case of the first FET 541.
(0049) The drains (D) of the first, third, and fifth FETs 541, 543, and 545 (upper arm FETs) are connected to the plus (+) terminal of the motor power supply 5. Furthermore, the sources (S) of the second, fourth, and sixths FETs 542, 544, and 546 (lower arm FETs) are connected to the minus (–) terminal of the motor power supply 5.
(0050) The aforementioned first shorting auxiliary circuit 80A comprises a npn type transistor (hereinafter referred to as first transistor) 70 and a pnp type transistor (hereinafter referred to as second transistor) 71. The emitter (E) of the first transistor 70 and the emitter (E) of the second transistor are connected, and the connection area thereof is connected to the gates (G) of the second, fourth, and sixths FETs 542, 544, and 546 (lower arm FETs) (in Figure 8, only the second FET 542 is excited). The base (B) of the first transistor 70 and the base (B) of the second transistor are connected, and the connection area thereof is connected to the control wire 90 of the PWM signal generator 45. The collector (C) of the first transistor 70 is connected to a 15 V FET gate driving power supply 92. The collector (C) of the second transistor 71 is grounded.
(0051) Series-connected diode 67 and resistor 68 are connected in parallel to the drains (D) and gates (G) of the second, fourth, and sixths FETs 542, 544, and 546 (lower arm FETs). A grounded Zener diode 69 is connected to the gates (G) of the second, fourth

and sixths FETs 542, 544, and 546, preventing the application of high voltage of any of the aforementioned gates (G). A capacitor 93 is connected in parallel to each Zener diode 69.

(0052) In this second mode of embodiment, as discussed below, shorting of the U-phase coil, V-phase coil, and W-phase coil is achieved by means of the first shorting auxiliary circuit 80A, and the first and second relays 65 and 66 (shorting circuit 80) used in the first mode of embodiment described above are eliminated. In this second mode of embodiment, for example if an open circuit occurs in the control wire 90 for the second FET 542, the first and second transistors 70 and 71 will not operate, since no voltage will be applied to their bases (B). In such a case, a stroke of the suspension unit 2 will cause the motor 3 to act as an electric generator, counter-electromotive voltage will arise between phases U and V, and if the U-phase voltage is higher, U-phase counter-electromotive voltage will be applied to the drain (D) of the second FET 542.

(0053) Furthermore, voltage is applied to the gate (G) of the second FET 542 through diode 67 and resistor 68, making it possible to make the second FET 542 conduct (turn it on). As a result, current will flow from the drain (D) side of the second FET 542 to the source, and current will flow to the V-phase coil and W-phase coil through the freewheeling diode 91 comprised in the fourth FET 544 corresponding to the V-phase coil (in other words the U-phase coil, V-phase coil, and W-phase coil will assumed a shorted state), and the suspension unit 2 will generate damping force.

(0054) It will be noted that counter-electromotive voltage is applied to the gate (G) of the second FET 542 through diode 67 during normal operation as well, but since the second and first transistors 70 and 71 operate, if the resistance value of resistor 68 is made adequately large, the switching operation of the second FET 542 will not be affected. In other words, if the power cable 81 connected to the motor 3 becomes open-circuited, strokes made by the suspension unit 2 will cause the motor 3 to act as an electric generator, the second FET 542 will automatically conduct (turn on) due to counter-electromotive voltage, the coils of each phase will be shorted, and current will flow, as a result of which, the suspension unit 2 will generate damping force.

(0055) In this second mode of embodiment, even if the gate control signal of the second FET 542 of the driver 4 experiences an open circuit, using the counter-electromotive voltage of the motor 3 to make the second FET 542 conduct (turn it on) makes it possible for damping force to be generated even if there is an open circuit. It will be noted that since the counter-electromotive voltage of motor 3 is used, it will not be possible of course to cause the second FET 542 to conduct (turn it on) if the suspension unit is not making strokes, or if the stroke speed is low and the counter-electromotive voltage is low. Thus, it will not be possible to generate damping force when the stroke speed is low.

(0056) Next, a third mode of embodiment of the present invention will be described based on Figure 9 and Figure 10. The electromagnetic suspension device of the third mode of embodiment, as shown in Figure 9 and Figure 10, eliminates the FET gate driving power supply 92 of the second mode of embodiment and is made such that the lower arm FETs, i.e. the second, fourth and sixth FETs 542, 544, and 546 (in the following, for the sake of expediency, the second FET 542 will be used as the example for description) can conduct (turn on) even when the stroke speed of the suspension unit 2 is low and the counter-electromotive voltage is low, allowing damping force to be generated even in the low range of stroke speed.

(0057) The third mode of embodiment has FET circuit 49B instead of the FET circuit 49A in the second mode of embodiment. FET circuit 49B has a second shorting auxiliary circuit 80B instead of the first shorting auxiliary circuit 80A of FET circuit 49A. The second shorting auxiliary circuit 80B has a third and fourth transistors 72 and 73 instead of the second and first transistors 70 and 71 of the first shorting auxiliary circuit 80A. The emitters of the third and fourth transistors 72 and 73 are connected, and the connection area thereof is connected to the gate of the second FET 542. The bases of the third and fourth transistors 72, 73 are connected, and to the connection area thereof is connected the collector of an npn type fifth transistor 95 with a grounded emitter. Control wire 90 is connected to the base (B) of the fifth transistor 95.

(0058) The collector of the third transistor 72 and the drain of the second FET 542 are connected across series-connected diode 74 and resistor 75. The collector and emitter of the third transistor 72 are connected via a resistor 78. One end of capacitor 76, whereof the other end is grounded, is connected to the connection area of resistor 78 and resistor 75. Zener diode 77 is connected in parallel to capacitor 76. Furthermore, the collector of the third transistor 72 and the collector of the fifth transistor 95 are connected across resistor 96.

(0059) In this third mode of embodiment, when the drain voltage of the second FET 542 is high, in other words, when a voltage is applied to the drain of the second FET 542 due to counter-electromotive voltage of the motor 3, or when the first FET 541 on the upper arm side is on, a charge accumulates in capacitor 76 through diode 74 and resistor 75. This voltage is set to a voltage adequately capable of driving the gate of the second FET 542, and is maintained at a constant voltage by Zener diode 77.

(0060) The voltage accumulated in capacitor 76 serves as a power supply for gate driving, and the gate of the second FET 542 is driven by the third and fourth transistors 72 and 73. The gate control signal has negative logic: the gate of the second FET 542 turns on when the gate control signal is at low level and turns off when the gate control signal is at high level. If the gate signal ceases to be generated due to open circuit or the like, the voltage accumulated in the capacitor 76 is applied to the gate of the second FET 542 via resistor 78, the second FET 542 is turned on,

and damping force is generated. In such cases, even if the stroke speed of the suspension unit 2 is low and counter-electromotive voltage is low, the lower arm FETs, i.e. the second, fourth, and sixth FETs 542, 544, and 546 (in the following, for the sake of expediency, the second FET 542 will be used as the example for description) are able to conduct (able to turn on), allowing damping force to be generated even in the low range of stroke speed.

(0061) The above first through third modes of embodiment were examples of cases where the suspension unit 2 had a cylindrical linear motor structure, but a suspension unit 2A as shown in Figure 11 may be used instead. The suspension unit 2A shown in Figure 11 comprises an outer cylinder member 20A; a cylindrical rod 21A whereof one end is inserted into outer cylinder member 20A and the other end protrudes from the outer cylinder member 20A; a ball nut 165 secured to one end of the rod 21A; and a ball screw 167 which engages with ball nut 165 and is rotatably supported via bearing 166 by the outer cylinder member 20A. Suspension unit 2A further comprises a permanent magnet 23A secured to a shaft 168 coaxial with ball screw 167; a coil 22A secured to the outer cylinder member 20A; and an unillustrated core material provided inside coil 22A. An annular guide member 69 is installed at the open end of the outer cylinder member 20A, and a sliding part 170 which slides over rod 21A and guides rod 21A is provided on the inside of guide member 169.

(0062) In this suspension unit 2A, electrification of coil 22A causes electromagnetic force to be generated between coil 22A and permanent magnet 23A, the permanent magnet 23A (shaft 68) and thus the ball screw 167 rotate, and as a result, the rod 21A is axially displaced relative to outer cylinder member 20A via ball nut 165, generating propulsive force and making it possible to improve the vibration suppressing effect.

Furthermore, if the rod 21A and outer cylinder member 20A undergo relative displacement in the axial direction due to vertical vibration of the vehicle body, the axial movement is converted to rotary movement by the ball nut 165 and ball screw 167, the permanent magnet 23A (shaft 168) rotates, electromotive force is generated in coil 22A, and resistance, in other words damping force, is generated according to the relative speed of the rod 21A and outer cylinder member 20A.

(0063) The first through third modes of embodiment described above used examples where the U-phase coil, V-phase coil, and W-phase coil are shorted in case of uncontrolled operation. For this shorting, one may also insert a resistor and consume the power generated when the motor 3 operates as an electrical generator.

(0064)

(EFFECT OF THE INVENTION) According to the invention described in claim 1, a shorting circuit is provided which causes the coil member to form a closed loop in cases of error in the signals supplied to the suspension unit, such as in cases of an open-circuited cable, which makes it possible to obtain damping force through electromotive force generated in the coil member due to strokes of the suspension unit, making it possible to avoid states of no damping force which could occur in the prior art in case of fault. Furthermore, according to the invention described in claim 2, the shorting circuit is provided integrally with the suspension unit, thereby making it possible to actuate the shorting circuit even when a fault has occurred in the control means or cables.

(BRIEF DESCRIPTION OF THE DRAWINGS)

(Figure 1) A drawing schematically showing the electromagnetic suspension device according to a first mode of embodiment of the present invention.

(Figure 2) A cross-sectional view showing the suspension unit of Figure 1.

(Figure 3) A block diagram schematically showing the control device of Figure 1.

(Figure 4) A block diagram schematically showing the driver of Figure 1.

(Figure 5) A diagram showing the shorting circuit of the electromagnetic suspension device of Figure 1, which employs relays.

(Figure 6) A flow chart representing the operation of the electromagnetic suspension device of Figure 1.

(Figure 7) A drawing schematically showing the electromagnetic suspension device according to a second mode of embodiment of the present invention.

(Figure 8) A drawing illustrating the first shorting auxiliary circuit of Figure 7.

(Figure 9) A drawing schematically showing a third mode of embodiment of the present invention.

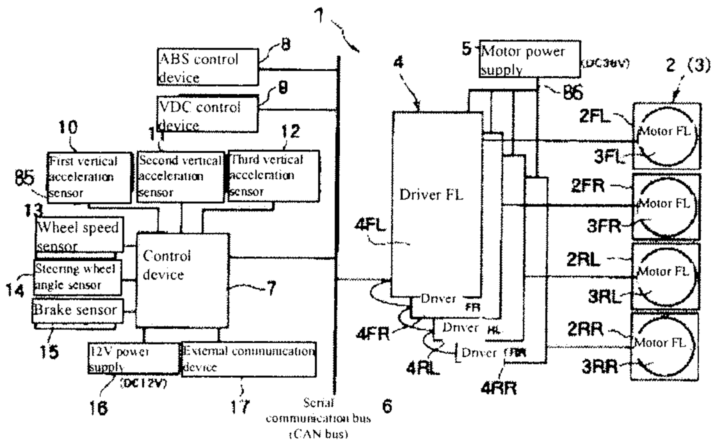
(Figure 10) A drawing illustrating the second shorting auxiliary circuit of Figure 8.

(Figure 11) A cross-sectional view showing another suspension unit that replaces the suspension unit of Figure 2.

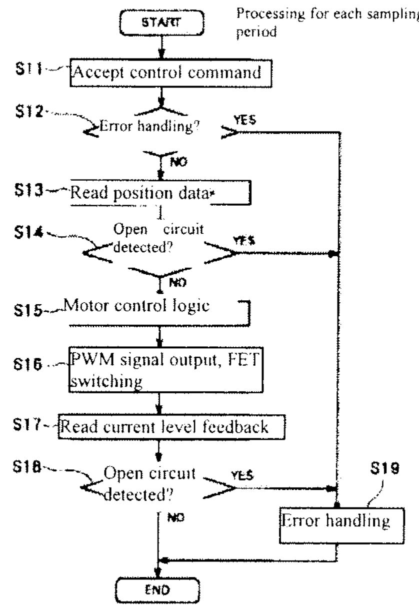
(EXPLANATION OF REFERENCES)

1 Electromagnetic suspension device
2 Suspension unit
3 Motor
22 Coil (coil member)
23 Permanent magnet (magnet member)
65 First relay (shorting circuit)
66 Second relay (shorting circuit)

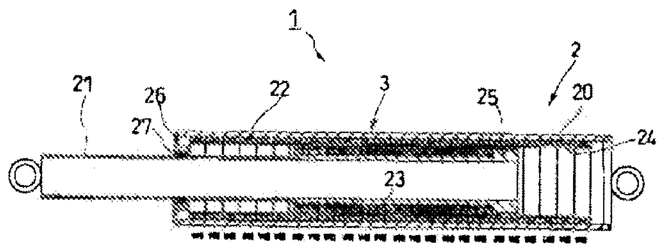
(Figure 1)



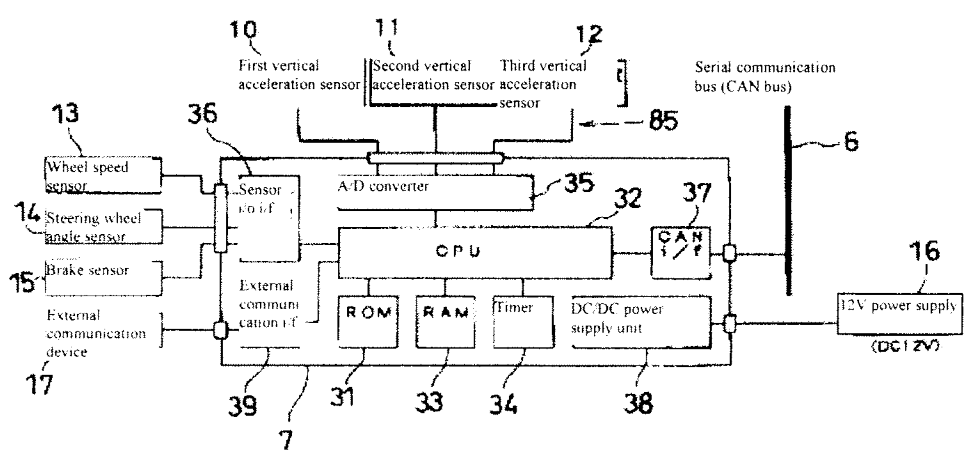
(Figure 6)



(Figure 2)



(Figure 3)



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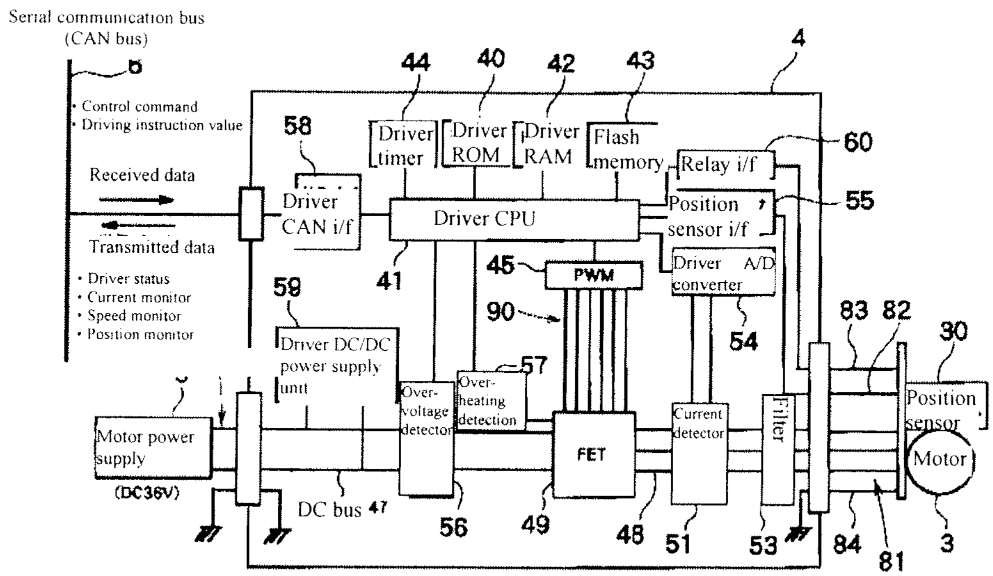
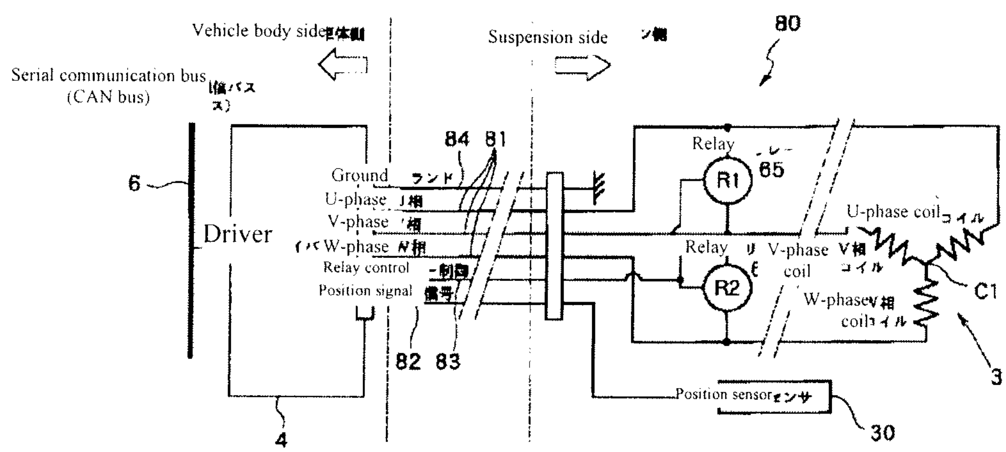


(Figure 5)



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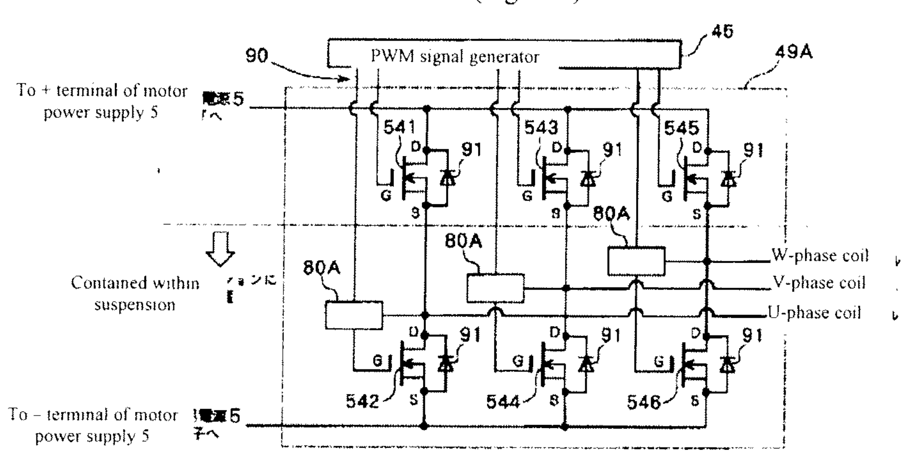
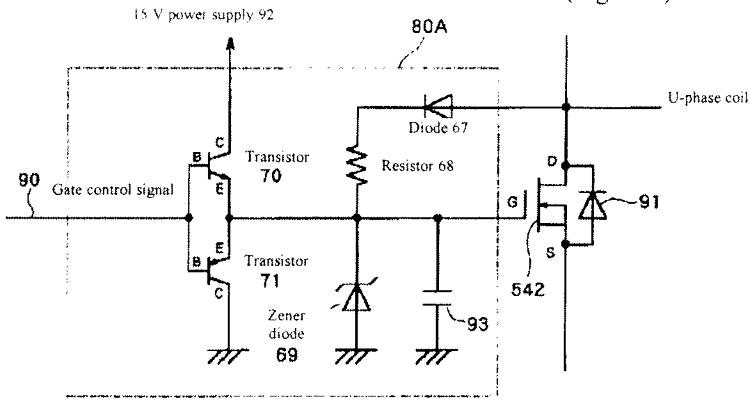
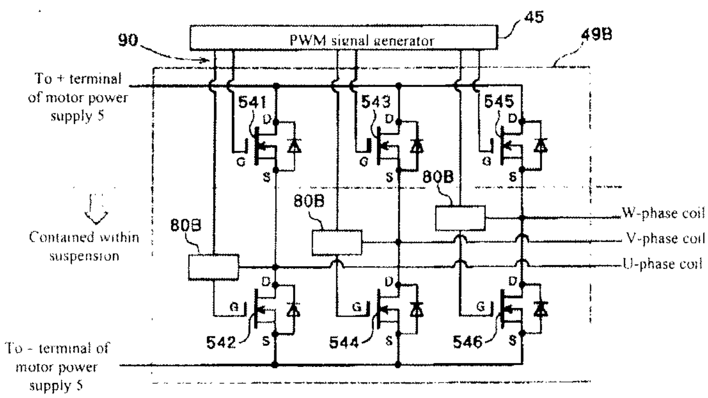


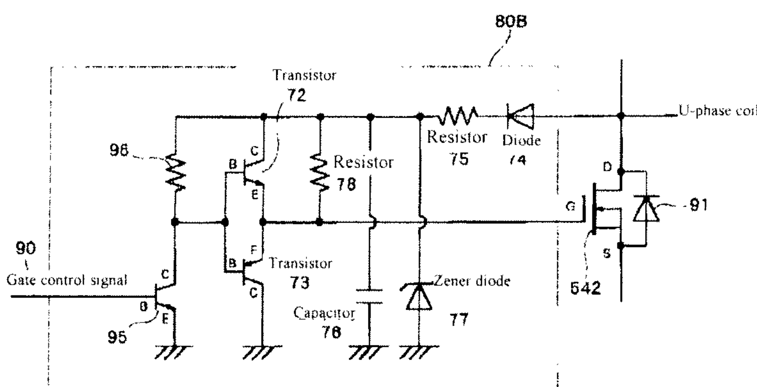
(Figure 8)



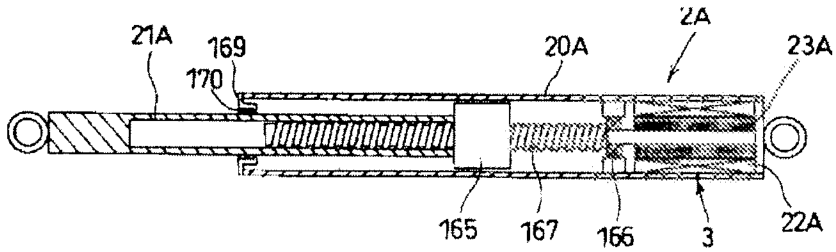
(Figure 9)



(Figure 10)



(Figure 11)



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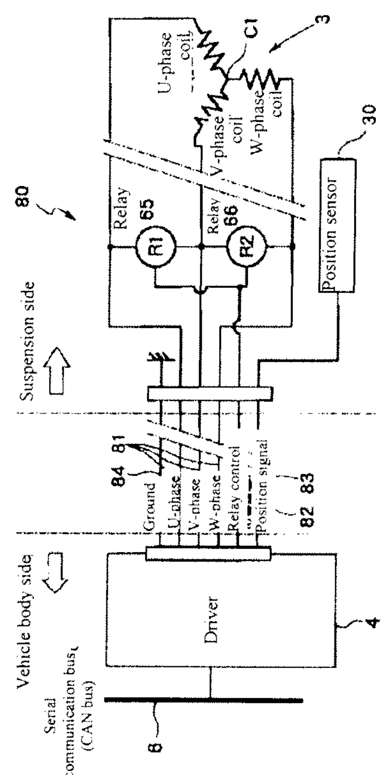
(54) (TITLE OF THE INVENTION) Electromagnetic suspension apparatus

(57) (ABSTRACT)

(PROBLEM) To provide an electromagnetic suspension apparatus capable of generating a damping force with a motor when control of the electromagnetic suspension apparatus is impossible due to an open circuit in a cable, etc. (during uncontrolled operation).

(MEANS FOR SOLVING) If an open circuit in power cable 81 is detected, a relay control signal is turned off, closing first and second relays 65 and 66 and shorting a U-phase coil, V-phase coil, and W-phase coil via first and second relays 65 and 66. Thus, when the suspension unit makes a stroke, a motor 3 provided on the suspension unit acts as an electric generator, generating resistance, in other words a damping force, of a magnitude substantially proportional to the stroke speed.



(SCOPE OF PATENT CLAIMS)

(CLAIM 1) An electromagnetic suspension apparatus comprising a suspension unit, which is provided with a pair of displacement members capable of relative displacement,

with a magnet member being provided on one of said pair of displacement members and a coil member which together with said magnet member constitutes a motor being provided on the other displacement member, and which obtains propulsive force through electromagnetic force generated between said coil member and said magnet member due to electrification of said coil member and obtains damping force through electromotive force generated in said coil member due to relative displacement of said coil member and said magnet member; and a control means which controls electrification of said suspension unit, said electromagnetic suspension apparatus being characterized in that it is provided with an error detection means which detects errors in the signal provided from the control means to the suspension unit, and a shorting circuit which causes the coil member to form a closed loop.

(CLAIM 2) The electromagnetic suspension apparatus described in claim 1, characterized in that said control means is provided on the vehicle body side, said control means being connected to said suspension unit with a cable, and said shorting circuit is provided integrally with the suspension unit.

(DETAILED DESCRIPTION OF THE INVENTION)

(0001)

(TECHNICAL FIELD OF THE INVENTION) The present invention concerns actuators and dampers for vibration suppression using electromagnetic force, and particularly relates to electromagnetic suspension apparatus suitable for use in automobiles, motorcycles, rail cars, structures, buildings, etc.

(0002)

(PRIOR ART) Examples of conventional electromagnetic suspension apparatus include electromagnetic suspension apparatus which, instead of a damping force generating mechanism such as the orifice of a hydraulic damper, employ a linear motor, or a rotary motor and a linear-rotary motion conversion mechanism which converts the rotary motion of the rotor of the rotary motor to linear motion. Electrifying such an electromagnetic suspension apparatus causes displacement of the movable parts and makes the motor actively operate as a motor proper (an actuator), while using the motor as an electric generator (passively) generates damping force.

(0003) When the motor is used as an electric generator, the resistance, in other words the damping force, generated by the motor (electric generator) is proportional to the magnitude of the current flowing to the coil, so the damping force can be made variable by adjusting the magnitude of the current flowing to the coil. Adjustment of the current flowing to the coil can be easily implemented, for instance, by providing a variable resistor within the circuit, or providing a switch which turns the circuit on and off and controlling the on-off time ratio of the switch.

(0004) Thus, variably controlling the damping force of an electromagnetic suspension apparatus according to the stroke speed and stroke position, or variably controlling it in real time to suppress vibration of the control target so as to provide as a so-called semi-active damper is relatively easy. Furthermore, when it is configured as a semi-active damper in this manner (used as an electric generator), there is no need to provide electric energy to the electromagnetic suspension apparatus, making it possible to greatly reduce power consumption.

(0005) Furthermore, if an electromagnetic suspension apparatus is provided with electrical energy and used as a motor, it is easy to generate an arbitrary force, which makes it possible to apply force so as to increase the damping force, or generate an arbitrary control force to operate the apparatus as an active suspension and increase the vibration suppression effect, and methods of increasing the vibration suppression effect in this manner have been proposed as well. Direct current motors and synchronous motors are used as motors in the above-described electromagnetic suspension apparatus.

(0006)

(PROBLEM TO BE SOLVED BY THE INVENTION) The drive system, excluding the sensor section, in the aforementioned electromagnetic suspension apparatus mainly consists of a power supply, a motor driving circuit and a motor which generates propulsive force and damping force. Currently, a power supply and motor are difficult to integrate and are separated, so a cable joining the power supply and motor to each other becomes necessary. Normally, the connections between power supply unit and motor driving circuit and between motor driving circuit and motor are made with cables. However, if these cables become open-circuited or if an open circuit occurs within the motor driving circuit (in case of uncontrolled operation), there is the problem that the motor is not only unable to generate propulsive force but also cannot generate damping force, so the motor assumes an undamped state. Furthermore, there is the problem that if the ignition key is not turned on, or in cases of a dead battery or the like (in case of uncontrolled operation), no power is supplied to the motor driving circuit or motor, and the motor assumes an undamped state, just as described above.

(0007) The present invention was made in view of the circumstances described above, its object being to provide an electromagnetic suspension apparatus capable of generating a damping force with the motor when control of the electromagnetic suspension apparatus is impossible due to an open circuit in a cable or the like (during uncontrolled operation).

(0008)

(MEANS FOR SOLVING THE PROBLEM) The invention described in claim 1 is an electromagnetic suspension apparatus comprising a suspension unit, which is provided with a pair of displacement members capable of relative displacement, with a magnet member being provided on one of said pair of displacement members and a coil member which together with said magnet member constitutes a motor being provided on the other displacement member, and which obtains propulsive force through electromagnetic force generated between said coil member and said magnet member due to electrification of said coil member and obtains damping force through electromotive force generated in said coil member due to relative displacement of said coil member and said magnet member; and a control means which controls electrification of said suspension unit, said electromagnetic suspension apparatus being characterized in that it is provided with an error detection means which detects errors in the signal provided from the control means to the suspension unit, and a shorting circuit which causes the coil member to form a closed loop. The invention described in claim 2 is characterized in that, in the configuration described in claim 1, said control

means is provided on the vehicle body side, said control means being connected to said suspension unit with a cable, and said shorting circuit is provided integrally with the suspension unit.

(0009)

(MODES OF EMBODIMENT OF THE INVENTION) The electromagnetic suspension apparatus of a first mode of embodiment of the present invention will be described based on Figures 1 through 6.

(0010) In Figure 1 and Figure 2, electromagnetic suspension apparatus 1 is used in automobiles, and has four suspension units mounted between each wheel side member and the vehicle body. The suspension units corresponding to the right front wheel side member, left front wheel side member, right rear wheel side member, and left rear wheel side member will be referred to respectively as the right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side suspension units 2FR, 2FL, 2RR, and 2RL. The right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side suspension units 2FR, 2FL, 2RR, and 2RL are each provided with a three-phase synchronous motor (respectively referred to as right front wheel side, left front wheel side, right rear wheel side and left rear wheel side motors 3FR, 3FL, 3RR and 3RL) comprising a star-connected U-phase coil, V-phase coil and W-phase coil (references omitted). The right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side suspension units 2FR, 2FL, 2RR and 2RL have the same configuration, and may be referred to below collectively as suspension unit 2. Furthermore, the right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side motors 3FR, 3FL, 3RR, and 3RL may be similarly referred to collectively as motor 3.

(0011) A driver is connected to the right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side motors 3FR, 3FL, 3RR and 3RL (referred to respectively as right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side drivers 4FR, 4FL, 4RR and 4RL) to drive the motors 3. The right front wheel side, left front wheel side, right rear wheel side, and left rear wheel side drivers 4FR, 4FL, 4RR and 4RL have the same configuration, and may be referred to hereinafter collectively as driver 4. A driver 4 is provided on the suspension tower part corresponding to each wheel. The drivers 4 are connected to a DC 36V motor power supply 5.

(0012) A control device 7 (vibration and attitude control means) is connected as a control means to the driver 4 via serial communication bus 6, and operational instructions from the control device 7 to the driver 4 and various types of feedback from the driver 4 to the control device 7, etc. is all performed through serial communication (for example, serial communication based on the CAN (Controller Area Network) specification). In the serial communication protocol, a "command" from control device 7 and a "response" from driver 4 form a set, and a "command" and "response" are exchanged every set time interval (e.g. 5 ms) (in every control period of the control device 7).

(0013) Furthermore, for example, if no "command" from the control device 7 to the driver 4 is transmitted for more than a set period of time (e.g. 20 ms), or if no "response" is transmitted from the driver 4 to the control device 7 for more than a set period of time (e.g. 20 ms), a system error is deemed to exist in the control device 7 or driver 4, and error handling such as "disconnection of motor power supply 5," "error display," etc. is carried out. An ABS (Anti-lock Brake System) control device 8 and VDC (Vehicle Dynamics Control) control device 9 are connected to the serial communication bus 6. The ABS control device 8 and VDC control device 9 ensure vehicle travel stability. The electromagnetic suspension apparatus 1, ABS control device 8, and VDC control device 9 are capable of coordinated operation.

(0014) Control device 7 performs electrification of motor 7 and thus control of generation of propulsive force by motor 3, as well as control of damping force through electromotive force generation (use as an electric generator) of the motor 3. Three vertical acceleration sensors (hereinafter referred to as first, second and third vertical acceleration sensors) 10, 11, and 12 which detect vertical vibration of the vehicle body, wheel speed sensor 13, steering wheel angle sensor 14, brake sensor 15, and DC 12V power supply (hereinafter referred to as 12V power supply) 16 are connected to control device 7. An external communication device 17 used for system diagnosis and the like is also connected to the control device 7. The first vertical acceleration sensor 10 is provided on the right front wheel suspension tower part, the second vertical acceleration sensor 11 is provided on the left front wheel suspension tower part, and the third vertical acceleration sensor 12 is provided in the rear trunk part.

(0015) Suspension unit 2, as shown in Figure 2, comprises an outer cylinder member 20 (one of the pair of displacement members) retained on the vehicle body side of the vehicle, and a rod 21 (the other of the pair of displacement members), whereof one end fits into the outer cylinder member 20 in a way that allows relative displacement and whereof the other end is supported on the vehicle axle side of the vehicle. A plurality of coils 22 (coil member) is provided over a predetermined length in the axial direction so as to lie between the outer cylinder member 20 and rod 21, and a permanent magnet (magnet member) 23 is provided over a predetermined length in the axial direction on the outside of the rod 21.

(0016) A cylindrical guide member (hereinafter referred to as first guide member) 24 is provided between the coils 22 and the rod 21 (permanent magnet 23), and a sliding part (hereinafter referred to as first sliding part) 25 which slides over the first guide member 24 is provided on one end of the rod 21. An annular guide member (hereinafter referred to as second guide member) 26 is installed on the open end of the outer cylinder member 20. A sliding part (hereinafter referred to as second sliding part) 27 which slides over the rod 21 and guides the movement thereof is provided on the inside of the second guide member 26. Rod 21 is slidably supported in relation to outer cylinder member 20 by first sliding part 25 and second sliding part 27.

(0017) The coils 22 are configured with a U-phase, V-phase, and W-phase alternating in the axial direction. Permanent magnet 23 is configured with an N pole and S pole alternating in the axial direction. When the coils 22 are electrified, thrust is generated in the axial direction between the coils 22 and the permanent magnet 23, and the outer cylinder member 20 and rod 21 undergo a relative displacement (stroke). The direction of the thrust is determined based on the direction of electrification of the coils 22. In the present mode of embodiment, the aforementioned motor 3 comprises the coils 22, permanent magnet 23, the outer cylinder member 20 which supports coils 22, the rod 21 which supports the permanent magnet 23, etc. Furthermore, when the outer cylinder member 20 and rod 21, and thus the coils 22 and permanent magnet 23, undergo relative displacement, electromotive force is generated in the coils 22 and the motor 3 acts as an electric generator. Motor 3 or suspension unit 2 is provided with a position sensor 30 (see Figure 4), allowing the detection of relative displacement (stroke) of coils 22 and permanent magnet 23, or of the outer cylinder member 20 and rod 21.

(0018) Control device 7 comprises a ROM 31 which stores fixed data such as constants and the control program of the electromagnetic suspension apparatus 1; a CPU 32 which executes the control program and exercises overall control of the electromagnetic suspension apparatus 1; RAM 33, which temporarily stores the computations results of CPU 32 and the like; and timer 34, which generates the sampling times, etc. Control device 7 additionally comprises an A/D converter 35 which converts the analog signals from the first, second, and third vertical acceleration sensors 10, 11, and 12 to digital signals; a sensor i/o interface (sensor i/o i/f) 36 which processes signals from wheel speed sensor 13, steering wheel angel sensor 14, and brake sensor 15; a CAN interface 37 for serial communication with the drivers 4, etc.; DC/DC power supply unit 38 which provides conversion from 12 V power supply 16 to 5 V, 3.3 V or other voltages required by the CPU 32, etc.; and external communication device interface 39, which exchanges signals with external communication device 17. In the present mode of embodiment, the power consumption limitation means is constituted as a sequence within the control program of control device 7 stored in ROM 31.

(0019) In the present electromagnetic suspension apparatus 1, among the states of the vehicle, vertical vibration of the vehicle body is detected by the first, second, and third vertical acceleration sensors, as discussed above. Furthermore, the magnitude of rolling and pitching of the vehicle body is evaluated on the basis of the detection signal of the aforementioned position sensor 30, or the stroke of the suspension unit 2 of each wheel. Furthermore, detection of the state of the vehicle is not limited to the aforementioned first, second, and third vertical acceleration sensors 10, 11, and 12 and position sensor 30, and is also performed using wheel speed sensor 13, steering wheel angle sensor 14, and brake sensor 15.

(0020) Based on the signals from the aforementioned first, second, and third vertical acceleration sensors 10, 11, and 12, the position sensor 30, the wheel speed sensor 13, the steering wheel angle sensor 14, and the brake sensor 15, the control device 7 determines the magnitude of control of the suspension unit 2 of each wheel and sends drive signals to the motors 3 of the drivers 4 so as to suppress vehicle vibration, attitude change, and unstable vehicle behavior, and to make the vehicle more stable in response to the vehicle speed and the driver's manipulation of the steering wheel, accelerator, and brake.

(0021) The driver 4, as shown in Figure 4, comprises a ROM (hereinafter referred to as driver ROM) 40 which stores fixed data such as constants and a motor drive control program; a CPU (hereinafter referred to as driver CPU) 41 which executes said motor drive control program, controls communication with the control device 7 and exercises control over the drivers 4; RAM (hereinafter referred to as driver RAM) 42 which temporarily stores the computation results, etc. of driver CPU 41; a flash memory 43 which stores rewritable parameters, etc. and is treated as specific to the vehicle and driver, etc.; and a timer (hereinafter referred to as driver timer) 44 which generates the sampling times, etc.

(0022) Driver 4 further comprises a PWM signal generator 45 for driving of motor 3; FET 49 which is connected to motor power supply 5 (DC 36 V) via DC bus 47, converts the current from the motor power supply 5 to three-phase current for use for driving the motor 3, and outputs this current through motor connection wire 48 to the motor 3; a current detector 51 which is provided on the motor connection wire 48 and detects the drive current of the motor 3; and a line filter 53 provided on the output side of the motor connection wire 48. Furthermore, driver 4 comprises an A/D converter (hereinafter referred to as driver A/D converter) 54 which converts analog signals from current detector 51 to digital signals; a position sensor interface (position sensor i/f) 55 which converts signals from the aforementioned position sensor 30 to digital signals and inputs them into driver CPU 41; and a relay interface (relay i/f) 60 which inputs relay control signals from driver CPU 41 into first and second relays 65 and 66.

(0023) First and second relays 65 and 66 comprise an excitation coil (not illustrated) which allows input of relay control signals; and a normally closed contact point (not illustrated) which opens and closes in response to the relay control signal inputted into the excitation coil, and are fashioned as normally closed relays. When the relay control signal of the excitation coil is on, the aforementioned contact point (and thus the first and second relays 65 and 66) opens (turns off). In this mode of embodiment, upon turning on the power supply (turning on the ignition switch) the relay control signal turns on and the first and second relays 65, 66 open (turn off); normally, this state (the state where the first and second relays 65, 66 are open (off)) is maintained. As will be discussed later, if a fault such an open circuit in a cable occurs (in case of uncontrolled operation), the relay control signal is turned off and the first and second relays 65, 66 are closed (turned on).

(0024) The driver 4 additionally comprises an overvoltage detector 56 which monitors the voltage of DC bus 47; an overheating detector 57 which detects overheating of FET 49; CAN i/f (hereinafter referred to as driver CAN interface) 58, which is an interface for serial communication with the control device 7; and a DC/DC power supply unit (hereinafter referred to as driver DC/DC power supply unit) 59 which performs conversion from motor power supply 5 to 5 V, 12 V, 15 V, or other voltages required for operation of the driver CPU 41 and other parts.

(0025) Upon receiving a control command such as "servo ON" and the control magnitude, etc. for actually driving the motor 3 from the control device 7 through serial communication bus 6, in every sampling time period (control period of driver 4), the driver 4 acquires operating speed of the motor 3 and the phase angle (electrical angle) between the magnetic circuit formed by the permanent magnet 23 and the U-phase, V-phase, and W-phase coils 22 within the motor 3 based on the signal of the position sensor 30, and the current level and voltage level of coils 22 based on the signal from the current detector 51, and regulates the PWM signal generator 45 so as to obtain motor operation according to the motor driving instruction from the control device 7. The aforementioned control period of the driver 4 is set at, for example, 250 μs, being substantially shorter than the control period of the control device 7 (e.g. 5 ms).

(0026) In this electromagnetic suspension apparatus 1, when the rod 21 and outer cylinder member 20 undergo relative displacement due to vertical vibration of the vehicle body, electromotive force is generated in the coils 22. Namely, the motor 3 acts as an electric generator, and current flows through the coils 22, as a result of which, the suspension unit 2 (motor 3) generates resistance, i.e. damping force, according to the relative speed of the rod 21 and outer cylinder member 20. Furthermore, in accordance with the relative positional relationship (electrical angle) of the rod 21 and outer cylinder member 20, and thus the vertical vibration state of the vehicle body, if current is supplied to the coils 22, the motor 3 will act as a motor proper (actuator) and produce propulsive force, allowing the vibration suppressing effect of the suspension unit 2 to be improved.

(0027) Figure 5 illustrates a circuit (shorting circuit) 80 which shorts the coils 22 in case of open circuit in a cable. The shorting circuit 80 comprises the aforementioned first relay 65 interposed between one end of the U-phase coil (the terminal part on the opposite side of the common contact terminal C1 of the U-phase coil, V-phase coil, and W-phase coil) and one end of the V-phase coil (the terminal part on the opposite side of the common contact terminal C1), and the aforementioned second relay 66 interposed between one end of the V-phase coil and one end of the W-phase coil (the terminal part on the opposite side of the common contact terminal C1), and is able to short the U-phase coil, V-phase coil and W-phase coil across the first and second relays 65 and 66, as discussed below. The shorting circuit 80 is provided in the suspension unit 2.

(0028) The suspension unit 2 (motor 3) and the driver 4 mounted on the vehicle body side are connected via power cable 81 that connects to the U-phase coil, V-phase coil, and W-phase coil of the motor 3; position signal cable 82 that extends from the position sensor 30; a cable (relay control cable) 83 for control of the first and second relays 65 and 66; and ground cable 84. Furthermore, first, second, and third vertical acceleration sensors 10, 11, and 12 and control device 7 are connected via acceleration signal cable 85. In this mode of embodiment, if any of the aforementioned cables (power cable 81, position signal cable 82, relay control cable 83, and acceleration signal cable 85) is open-circuited, or if a fault occurs such that no power is supplied from the battery (12 V power supply 16, motor power supply 5), etc. (such cases may be referred to hereinafter as power supply interruption) (in case of uncontrolled operation), the driver 4 turns off the relay control signal outputted to the first and second relays 65, 66.

(0029) As indicated above, the first and second relays 65 and 66 are normally closed relays, and the relay control signal from the driver 4 is normally turned on and outputted to keep the first and second relays 65 and 66 in an open (off) state. In this normal state, the first and second relays 65 and 66 are kept open, so the U-phase coil, V-phase coil, and W-phase coil are not shorted, and the motor 3 is normally controlled and is able to generate propulsive force (act as a motor proper) and damping force (act as an electric generator).

(0030) If no relay control signal is outputted from the driver 4 (if the relay control signal is off), the first and second relays 65 and 66 assume a closed (on) state (the same state as normally), and the U-phase coil, V-phase coil, and W-phase coil become shorted due to the closure (turning on) of the first and second relays 65 and 66. In other words, in case of uncontrolled operation as described above (open-circuiting of one of the aforementioned cables or power supply interruption), the driver 4 turns off the relay control signal outputted to the first and second relays 65 and 66, and the U-phase coil, V-phase coil, and W-phase coil assume a shorted state.

(0031) If the U-phase coil, V-phase coil, and W-phase coil are shorted, when the suspension unit 2 makes a stroke, the motor 3 acts as an electric generator and generates resistance, in other words damping force, of a magnitude substantially proportional to the stroke speed. Below, examples of specific open circuit locations will be used to explain the method of open circuit detection (error detection means) and the control method in such cases. Detection of open circuit in the power cable 81 (the cable between the driver 4 and motor 3) is performed as follows.

(0032) Namely, a current detector 51 is incorporated into the driver 4, which checks if the current level instructed by the driver CPU 41 is being accurately outputted to the U-phase coil, V-phase coil, and W-phase coil by detecting the outputted current, and feeds back the detected value to the driver CPU 41. If the

power cable 81 is open-circuited, the current level fed back to the driver CPU 41 will present an abnormal value (a value indicating zero or very low current level). The driver CPU 41 uses this fact to determine the presence or absence of open circuit in the power cable 81.

(0033) If the driver CPU 41 determines that an open circuit is present in the power cable 81 (if an open circuit has been detected in the power cable 81), it turns off the relay control signal, closing the first and second relays 65 and 66 and shorting the U-phase coil, V-phase coil, and W-phase coil through the first and second relays 65 and 66, and also stops the motor control and notifies the control device 7 about the open circuit detection.

(0034) Next, determination of open circuit in the position signal cable 82 is performed as follows. If the position sensor 30 is a sensor of the type that constantly outputs a signal (e.g. the signal varies between 1 and 5 V), the presence of an open circuit can be determined if no signal is being outputted. Furthermore, for instance, in the case of a 0–5 V A, B phase pulse position sensor or the like, or a sensor which has states in which no output signal is outputted, the determination of open circuit in the position signal cable 82 or failure of position sensor 30 can be determined if the output of the position sensor is 0 V or does not change despite the fact that its output should change based on the output from the vertical acceleration sensor, etc. connected to the control device 7. If open circuit in the position signal cable 82 is detected, the control device 7 issues a notification of motor control stop to the driver 4. The driver CPU 41 then performs shorting of the U-phase coil, V-phase coil, and W-phase coil, stoppage of motor control and notification of the control device 7 regarding open circuit detection, in the same manner as described above.

(0035) Open circuit in the relay control cable 83 is detected as follows. Here, in order to open (turn off) the first and second relays 65 and 66, it is necessary to pass an excitation current (a relay control signal whereof the content (signal level) is ON) through the relay control cable 83 and excite the excitation coils contained in the first and second relays 65 and 66. Open circuit in the relay control cable 83 is normally detected by monitoring the excitation current (relay control signal) by means of the relay i/f 60 inside driver 4. If open circuit in the relay control cable 83 is detected, no signal is supplied to the first and second relays 65 and 66, so these relays automatically close (return to their normal state), shorting the U-phase coil, V-phase coil, and W-phase coil. Furthermore, the driver CPU 41 turns off the relay control signal, stops motor control, and notifies the control device 7 about the open circuit detection. Here, the reason for turning off the relay control signal is that, while there would be no problem in cases of complete open circuit in the relay control cable, in cases of repeated open circuit followed by reconnection and open circuit, the first and second relays 65 and 66 will repeatedly open and close, and in order to prevent this, it is necessary to leave the relay control signal off.

(0036) Furthermore, open circuit in the acceleration signal cable 85 is detected as follows. In this mode of embodiment, the acceleration signal from the first, second, and third vertical acceleration sensors 10, 11, and 12 is set for instance to a signal output of 1 to 5 V, centered on 3 V, and when no signal is outputted from the first, second, and third vertical acceleration sensors 10, 11, and 12 (for example, when the output signal of the first, second, and third vertical acceleration sensors 10, 11, and 12 is 0 V), it is stipulated that an open circuit can be determined to exist in the acceleration signal cable 85. The driver CPU 41 performs detection of open circuit in the acceleration signal cable 85 based on the acceleration signals from the first, second, and third vertical acceleration sensors 10, 11, and 12. If an open circuit is detected, the driver CPU 41 performs shorting of the U-phase coil, V-phase coil, and W-phase coil, stoppage of motor control, and notification of the control device 7 regarding open circuit detection, in the same manner as described above.

(0037) Furthermore, if the control device 7 or driver 4 ceases to operate normally due to runaway operation or the like, the driver CPU 41 stops supplying power to the motor 3, closes the first and second relays 65 and 66, and puts the U-phase coil, V-phase coil, and W-phase coil into a shorted state. To determine the presence or absence of runaway operation, for example, the CPU is made to periodically access the relay i/f and PWM signal generator, and the relay i/f and PWM signal generator are provided with a function of determining the presence or absence of this periodic access and stopping the output in case of absence of the periodic access. As a result, in case of runaway operation, periodic access ceases to be performed, and thus the output from the relay i/f and PWM signal generator stops, supply of power to the motor 3 is discontinued, and the U-phase coil, V-phase coil, and W-phase coil are placed into a shorted state. Furthermore, if an open circuit occurs in the power supply cable 86 connecting the motor power supply 5 and the driver 4, and supply of power to the driver 4 stops, the relay control signal is turned off, the first and second relays 65 and 66 close, and the U-phase coil, V-phase coil, and W-phase coil are placed into a shorted state.

(0038) Furthermore, if an abnormal operation such as closing (turning on) of the first and second relays 65 and 66 due to some sort of factor occurs during normal operation of the system, a shorted loop (closed circuit) is formed before the U-phase coil, V-phase coil, and W-phase coil, and current ceases to be supplied from the driver 4 to the U-phase coil, V-phase coil, and W-phase coil. In such cases, excess current corresponding to the removed resistance of the coils 22 flows through the power cable 81, and current level feedback anomalies (excess current levels) are detected by current detector 51, so the driver CPU 41 detects errors in the first and second relays 65 and 66.

(0039) If an error is detected in the first and second relays 65 and 66, the driver CPU 41 performs shorting of the U-phase coil, V-phase coil, and W-phase coil, and stoppage of motor control and notification of the control device 7 regarding open circuit detection, in the same manner as described above.

(0040) The above operation will be summarized based on the flow chart of Figure 6. Driver CPU 41 accepts a control command from control device 7 (step S11) and determines if there is an error handling request from the control device 7 (step S12). If the decision in step S12 is No (if error handling is not necessary), the driver CPU 41 reads position data from position sensor 30 for control of motor 3 (step S13).

(0041) Based on the reading of position data in step S13, the presence or absence of open circuit in position signal cable 82 is determined (step S14). In the next step 15, motor control logic is executed, the positional relationship of the magnet 23 and the coils 22 of the motor 3 is ascertained based on position data, and the current levels, etc. of the U-phase coil, V-phase coil, and W-phase coil are ascertained based on current level feedback (before 1 sampling), and the control magnitude for the motor 3 is determined based on the required torque and speed of the motor 3, etc.

(0042) Next, FET 49 is switched via the PWM signal generator 45 to adjust the voltage impressed on the U-phase coil, V-phase coil, and W-phase coil and controls the motor 3 to generate the prescribed torque and attain the prescribed speed (step S16). Subsequently, current level feedback of the U-phase coil, V-phase coil, and W-phase coil is received by current detector 51 (step S17) and the presence/absence of open circuit is determined (step S18).

(0043) If the decision in step S12 is Yes (error handling is required), or if the decision in step S14 is Yes (open circuit is present), power to the motor 3 is cut, and error handling such as shorting of the first and second relays 65 and 66 and transmission of error handling status to the control device 7 is performed (step S19).

(0044) As discussed above, the suspension unit 2 is able to generate damping force even during so-called uncontrolled operation, such as in cases of power supply interruption, open circuit in a cable, dead battery (power supply interruption), runaway operation of the control device 7 and driver 4, or turning off of the ignition switch, thereby greatly improving safety.

(0045) If the type of first and second relays 65 and 66 selected is one which allows passing large currents, the risk of breakdown will be reduced. By using a relay type that allows passing of large currents for the first and second relays 65 and 66, the suspension unit will be able to generate stable damping force for a long time even during uncontrolled operation, further improving safety.

(0046) Next, a second mode of embodiment of the present invention will be described based on Figure 7 and Figure 8. The electromagnetic suspension device of the second mode of embodiment, as shown in Figure 7 and Figure 8, has an FET circuit 49A instead of the aforementioned FET 49. FET circuit 49A has six FETs (hereinafter referred to as first through sixth FETs) 541 through 546. The source (S) of the first FET 541 is connected to the drain (D) of the second FET 542, and the connection area thereof is connected to the U-phase coil. The source (S) of the third FET 543 is connected to the drain (D) of the fourth FET 544, and the connection area thereof is connected to the V-phase coil. The source (S) of the fifth FET 545 is connected to the drain (D) of the sixth FET 546, and the connection area thereof is connected to the W-phase coil.

(0047) Six control wires 90 extend from the PWM signal generator 45 to FET circuit 49A, three of which are connected to the gates (G) of the first, third, and fifth FETs 541, 543, and 545 (which may be referred to hereinafter as upper arm FETs). The other three signal wires 90 of the aforementioned six control wires 90 are connected to the gates (G) of the second, fourth, and sixths FETs 542, 544, and 546 via a shorting auxiliary circuit (hereinafter referred to as first shorting auxiliary circuit) 80A. In this second mode of embodiment, the first shorting auxiliary circuit 80A and the second, fourth and sixths FETs 542, 544, and 546 form the shorting circuit.

(0048) The first FET 541 comprises a freewheeling diode 91 which connects the source (S) and drain (D) and permits electricity to pass through the freewheeling diode 91 from the source (S) to the drain (D). A freewheeling diode is connected between the source and drain of the second through sixths FETs 542 through 546 as well, just as in the case of the first FET 541.

(0049) The drains (D) of the first, third, and fifth FETs 541, 543, and 545 (upper arm FETs) are connected to the plus (+) terminal of the motor power supply 5. Furthermore, the sources (S) of the second, fourth, and sixths FETs 542, 544, and 546 (lower arm FETs) are connected to the minus (–) terminal of the motor power supply 5.

(0050) The aforementioned first shorting auxiliary circuit 80A comprises a npn type transistor (hereinafter referred to as first transistor) 70 and a pnp type transistor (hereinafter referred to as second transistor) 71. The emitter (E) of the first transistor 70 and the emitter (E) of the second transistor are connected, and the connection area thereof is connected to the gates (G) of the second, fourth, and sixths FETs 542, 544, and 546 (lower arm FETs) (in Figure 8, only the second FET 542 is excited). The base (B) of the first transistor 70 and the base (B) of the second transistor are connected, and the connection area thereof is connected to the control wire 90 of the PWM signal generator 45. The collector (C) of the first transistor 70 is connected to a 15 V FET gate driving power supply 92. The collector (C) of the second transistor 71 is grounded.

(0051) Series-connected diode 67 and resistor 68 are connected in parallel to the drains (D) and gates (G) of the second, fourth, and sixths FETs 542, 544, and 546 (lower arm FETs). A grounded Zener diode 69 is connected to the gates (G) of the second, fourth

and sixths FETs 542, 544, and 546, preventing the application of high voltage of any of the aforementioned gates (G). A capacitor 93 is connected in parallel to each Zener diode 69.

(0052) In this second mode of embodiment, as discussed below, shorting of the U-phase coil, V-phase coil, and W-phase coil is achieved by means of the first shorting auxiliary circuit 80A, and the first and second relays 65 and 66 (shorting circuit 80) used in the first mode of embodiment described above are eliminated. In this second mode of embodiment, for example if an open circuit occurs in the control wire 90 for the second FET 542, the first and second transistors 70 and 71 will not operate, since no voltage will be applied to their bases (B). In such a case, a stroke of the suspension unit 2 will cause the motor 3 to act as an electric generator, counter-electromotive voltage will arise between phases U and V, and if the U-phase voltage is higher, U-phase counter-electromotive voltage will be applied to the drain (D) of the second FET 542.

(0053) Furthermore, voltage is applied to the gate (G) of the second FET 542 through diode 67 and resistor 68, making it possible to make the second FET 542 conduct (turn it on). As a result, current will flow from the drain (D) side of the second FET 542 to the source, and current will flow to the V-phase coil and W-phase coil through the freewheeling diode 91 comprised in the fourth FET 544 corresponding to the V-phase coil (in other words the U-phase coil, V-phase coil, and W-phase coil will assumed a shorted state), and the suspension unit 2 will generate damping force.

(0054) It will be noted that counter-electromotive voltage is applied to the gate (G) of the second FET 542 through diode 67 during normal operation as well, but since the second and first transistors 70 and 71 operate, if the resistance value of resistor 68 is made adequately large, the switching operation of the second FET 542 will not be affected. In other words, if the power cable 81 connected to the motor 3 becomes open-circuited, strokes made by the suspension unit 2 will cause the motor 3 to act as an electric generator, the second FET 542 will automatically conduct (turn on) due to counter-electromotive voltage, the coils of each phase will be shorted, and current will flow, as a result of which, the suspension unit 2 will generate damping force.

(0055) In this second mode of embodiment, even if the gate control signal of the second FET 542 of the driver 4 experiences an open circuit, using the counter-electromotive voltage of the motor 3 to make the second FET 542 conduct (turn it on) makes it possible for damping force to be generated even if there is an open circuit. It will be noted that since the counter-electromotive voltage of motor 3 is used, it will not be possible of course to cause the second FET 542 to conduct (turn it on) if the suspension unit is not making strokes, or if the stroke speed is low and the counter-electromotive voltage is low. Thus, it will not be possible to generate damping force when the stroke speed is low.

(0056) Next, a third mode of embodiment of the present invention will be described based on Figure 9 and Figure 10. The electromagnetic suspension device of the third mode of embodiment, as shown in Figure 9 and Figure 10, eliminates the FET gate driving power supply 92 of the second mode of embodiment and is made such that the lower arm FETs, i.e. the second, fourth and sixth FETs 542, 544, and 546 (in the following, for the sake of expediency, the second FET 542 will be used as the example for description) can conduct (turn on) even when the stroke speed of the suspension unit 2 is low and the counter-electromotive voltage is low, allowing damping force to be generated even in the low range of stroke speed.

(0057) The third mode of embodiment has FET circuit 49B instead of the FET circuit 49A in the second mode of embodiment. FET circuit 49B has a second shorting auxiliary circuit 80B instead of the first shorting auxiliary circuit 80A of FET circuit 49A. The second shorting auxiliary circuit 80B has a third and fourth transistors 72 and 73 instead of the second and first transistors 70 and 71 of the first shorting auxiliary circuit 80A. The emitters of the third and fourth transistors 72 and 73 are connected, and the connection area thereof is connected to the gate of the second FET 542. The bases of the third and fourth transistors 72, 73 are connected, and to the connection area thereof is connected the collector of an npn type fifth transistor 95 with a grounded emitter. Control wire 90 is connected to the base (B) of the fifth transistor 95.

(0058) The collector of the third transistor 72 and the drain of the second FET 542 are connected across series-connected diode 74 and resistor 75. The collector and emitter of the third transistor 72 are connected via a resistor 78. One end of capacitor 76, whereof the other end is grounded, is connected to the connection area of resistor 78 and resistor 75. Zener diode 77 is connected in parallel to capacitor 76. Furthermore, the collector of the third transistor 72 and the collector of the fifth transistor 95 are connected across resistor 96.

(0059) In this third mode of embodiment, when the drain voltage of the second FET 542 is high, in other words, when a voltage is applied to the drain of the second FET 542 due to counter-electromotive voltage of the motor 3, or when the first FET 541 on the upper arm side is on, a charge accumulates in capacitor 76 through diode 74 and resistor 75. This voltage is set to a voltage adequately capable of driving the gate of the second FET 542, and is maintained at a constant voltage by Zener diode 77.

(0060) The voltage accumulated in capacitor 76 serves as a power supply for gate driving, and the gate of the second FET 542 is driven by the third and fourth transistors 72 and 73. The gate control signal has negative logic: the gate of the second FET 542 turns on when the gate control signal is at low level and turns off when the gate control signal is at high level. If the gate signal ceases to be generated due to open circuit or the like, the voltage accumulated in the capacitor 76 is applied to the gate of the second FET 542 via resistor 78, the second FET 542 is turned on,

and damping force is generated. In such cases, even if the stroke speed of the suspension unit 2 is low and counter-electromotive voltage is low, the lower arm FETs, i.e. the second, fourth, and sixth FETs 542, 544, and 546 (in the following, for the sake of expediency, the second FET 542 will be used as the example for description) are able to conduct (able to turn on), allowing damping force to be generated even in the low range of stroke speed.

(0061) The above first through third modes of embodiment were examples of cases where the suspension unit 2 had a cylindrical linear motor structure, but a suspension unit 2A as shown in Figure 11 may be used instead. The suspension unit 2A shown in Figure 11 comprises an outer cylinder member 20A; a cylindrical rod 21A whereof one end is inserted into outer cylinder member 20A and the other end protrudes from the outer cylinder member 20A; a ball nut 165 secured to one end of the rod 21A; and a ball screw 167 which engages with ball nut 165 and is rotatably supported via bearing 166 by the outer cylinder member 20A. Suspension unit 2A further comprises a permanent magnet 23A secured to a shaft 168 coaxial with ball screw 167; a coil 22A secured to the outer cylinder member 20A; and an unillustrated core material provided inside coil 22A. An annular guide member 69 is installed at the open end of the outer cylinder member 20A, and a sliding part 170 which slides over rod 21A and guides rod 21A is provided on the inside of guide member 169.

(0062) In this suspension unit 2A, electrification of coil 22A causes electromagnetic force to be generated between coil 22A and permanent magnet 23A, the permanent magnet 23A (shaft 68) and thus the ball screw 167 rotate, and as a result, the rod 21A is axially displaced relative to outer cylinder member 20A via ball nut 165, generating propulsive force and making it possible to improve the vibration suppressing effect.

Furthermore, if the rod 21A and outer cylinder member 20A undergo relative displacement in the axial direction due to vertical vibration of the vehicle body, the axial movement is converted to rotary movement by the ball nut 165 and ball screw 167, the permanent magnet 23A (shaft 168) rotates, electromotive force is generated in coil 22A, and resistance, in other words damping force, is generated according to the relative speed of the rod 21A and outer cylinder member 20A.

(0063) The first through third modes of embodiment described above used examples where the U-phase coil, V-phase coil, and W-phase coil are shorted in case of uncontrolled operation. For this shorting, one may also insert a resistor and consume the power generated when the motor 3 operates as an electrical generator.

(0064)

(EFFECT OF THE INVENTION) According to the invention described in claim 1, a shorting circuit is provided which causes the coil member to form a closed loop in cases of error in the signals supplied to the suspension unit, such as in cases of an open-circuited cable, which makes it possible to obtain damping force through electromotive force generated in the coil member due to strokes of the suspension unit, making it possible to avoid states of no damping force which could occur in the prior art in case of fault. Furthermore, according to the invention described in claim 2, the shorting circuit is provided integrally with the suspension unit, thereby making it possible to actuate the shorting circuit even when a fault has occurred in the control means or cables.

(BRIEF DESCRIPTION OF THE DRAWINGS)

(Figure 1) A drawing schematically showing the electromagnetic suspension device according to a first mode of embodiment of the present invention.

(Figure 2) A cross-sectional view showing the suspension unit of Figure 1.

(Figure 3) A block diagram schematically showing the control device of Figure 1.

(Figure 4) A block diagram schematically showing the driver of Figure 1.

(Figure 5) A diagram showing the shorting circuit of the electromagnetic suspension device of Figure 1, which employs relays.

(Figure 6) A flow chart representing the operation of the electromagnetic suspension device of Figure 1.

(Figure 7) A drawing schematically showing the electromagnetic suspension device according to a second mode of embodiment of the present invention.

(Figure 8) A drawing illustrating the first shorting auxiliary circuit of Figure 7.

(Figure 9) A drawing schematically showing a third mode of embodiment of the present invention.

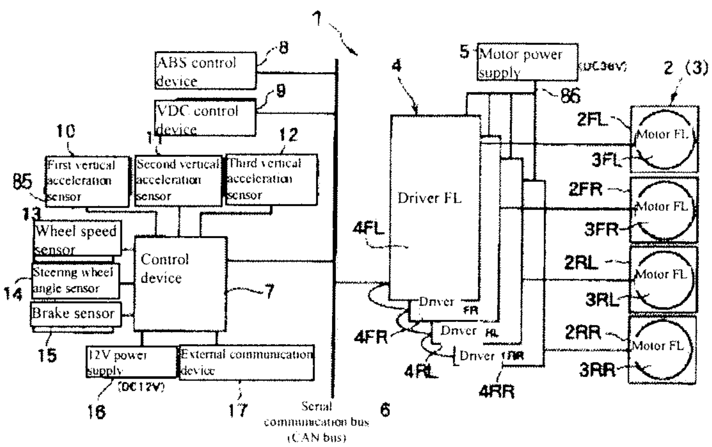
(Figure 10) A drawing illustrating the second shorting auxiliary circuit of Figure 8.

(Figure 11) A cross-sectional view showing another suspension unit that replaces the suspension unit of Figure 2.

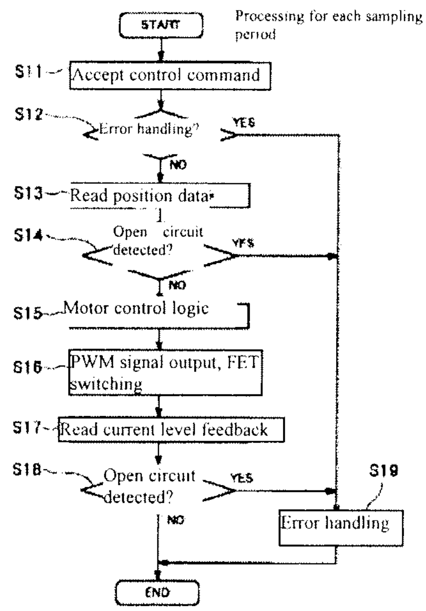
(EXPLANATION OF REFERENCES)

1 Electromagnetic suspension device
2 Suspension unit
3 Motor
22 Coil (coil member)
23 Permanent magnet (magnet member)
65 First relay (shorting circuit)
66 Second relay (shorting circuit)

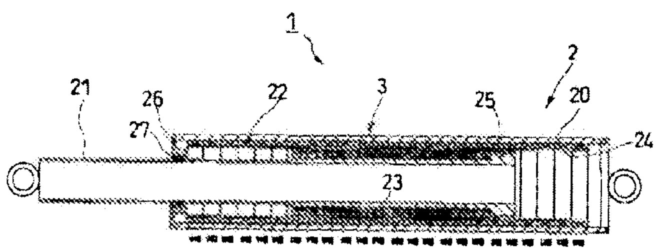
(Figure 1)



(Figure 6)



(Figure 2)



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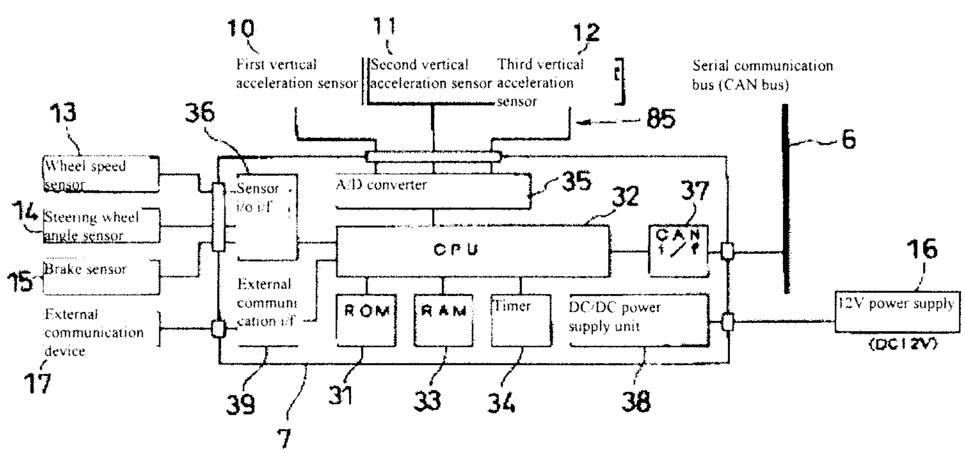

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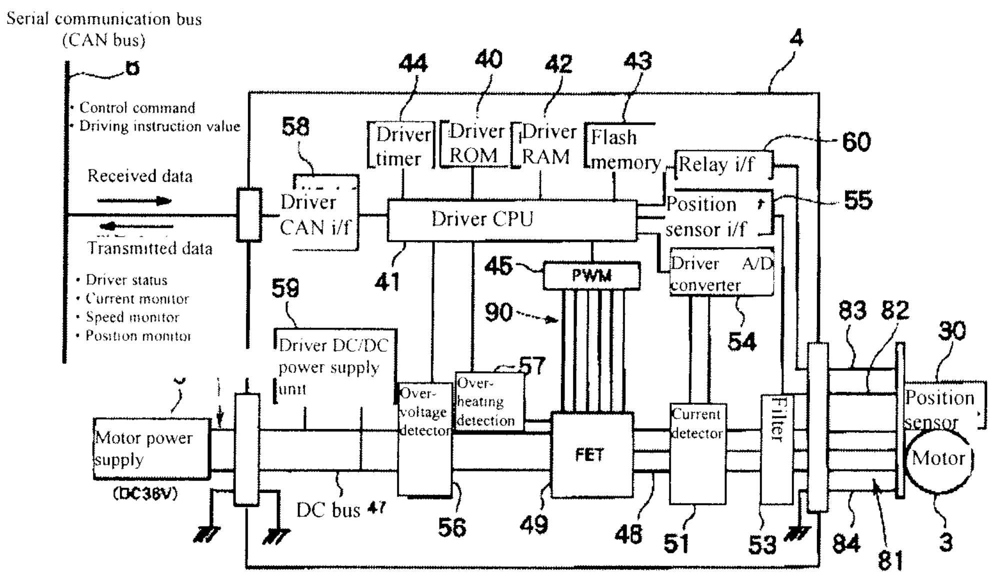

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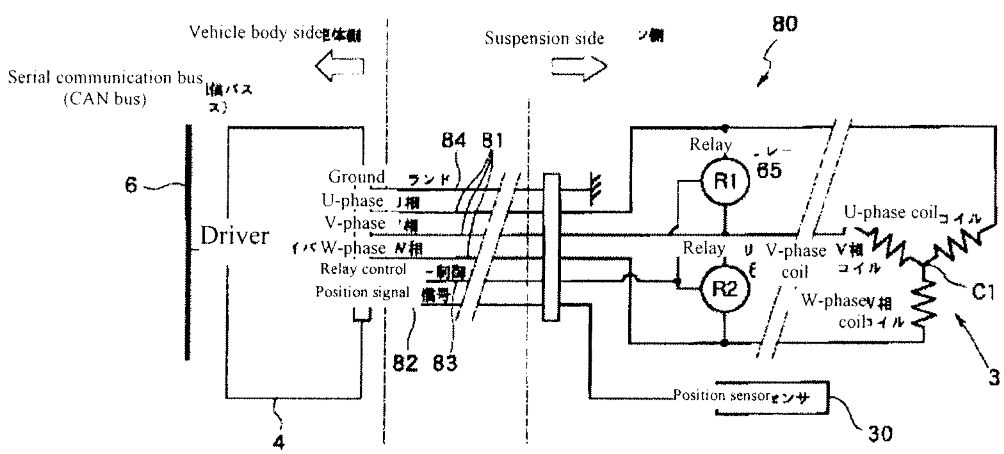

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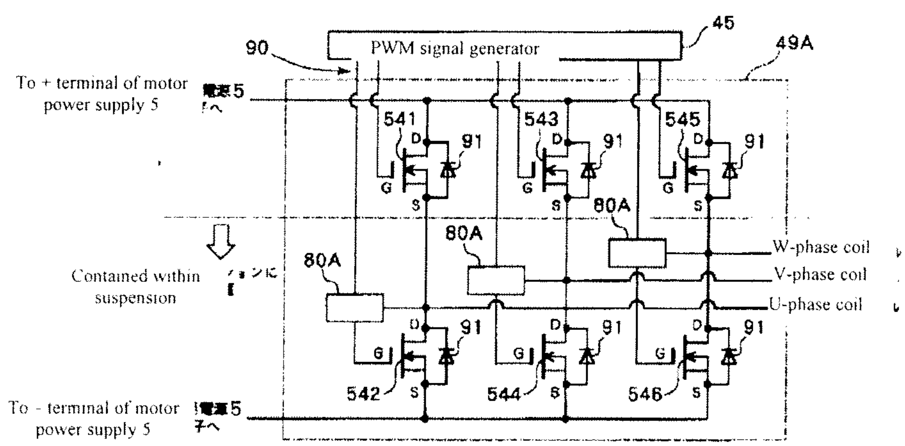
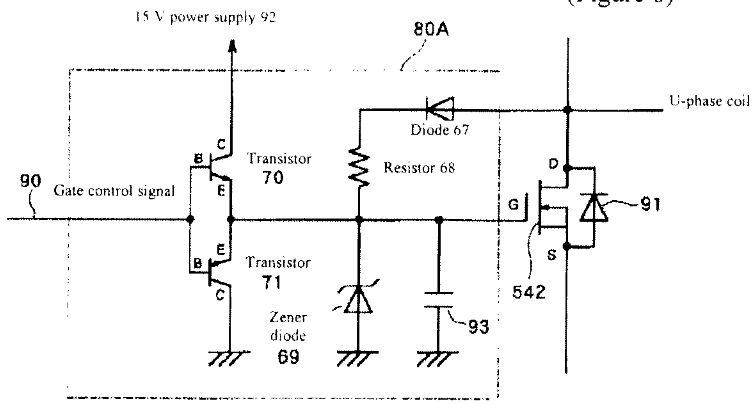


(Figure 8)



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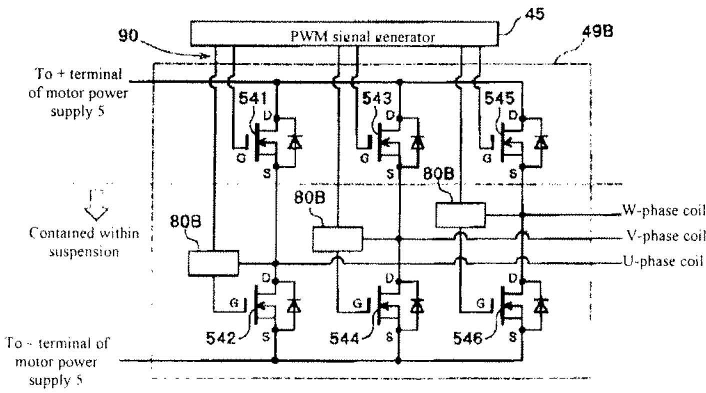

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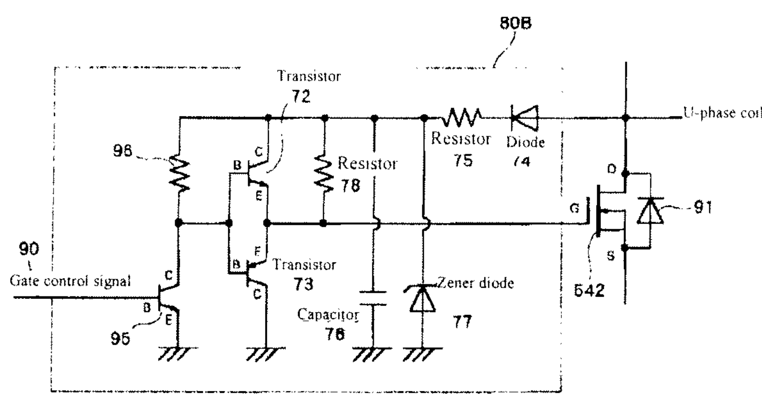
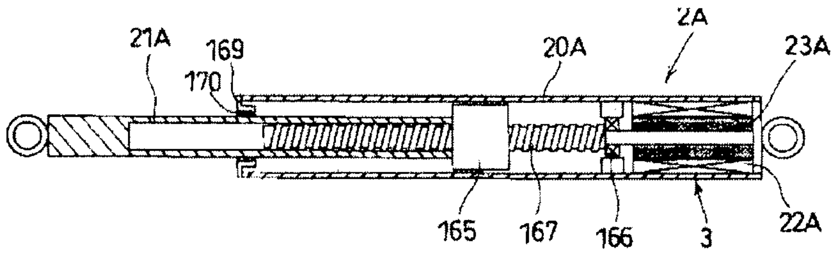


(Figure 11)



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F-terms (reference)

3D001 AA02 DA17 EA02 EA07 EA08
EA22 EA34 ED06
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